A 35 kw AIRBORNE ILLUMINATION SYSTEM (U)

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FOREWORD

This report was prepared by Union Carbide Corporation, Linde Division, Speedway Laboratories, Indianapolis, Indiana under USAF Contract No. AF 33(615)-3437. This work was administered under the Air Force Avionics Laboratory by Mr. H. R. Gedling and Lt. James W. Mayo III.

This report describes the 35 kw airborne illumination system designed, built and tested January 1, 1966-May 15, 1967 at the Speedway Research Laboratory, Linde Division, Union Carbide Corporation, Indianapolis, Indiana.

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A 35 kw AIRBORNE ILLUMINATION SYSTEM

1.0 INTRODUCTION AND SUMMARY

Results of a program to establish feasibility, fabricate and deliver an ultraviolet airborne illuminator are reported. The work, on Contract AF 33(615)-3437, has resulted in a flight weight package which has been satisfactorily operated in the laboratory at input powers of 20-35 kilowatts, in both the covert and visible modes. Succeeding sections of this report will discuss in detail the radiation source, optical system, auxiliaries, operating procedure and safety considerations.

The overall system is shown in Figure 1. Power from an aircraft three-phase, 400-cycle generator is supplied to the package. The small pilot's control box, also shown in Figure 1, enables the pilot to control illumination intensity and duration. Heat rejection is to ambient air, using a movable scoop. Internal sequencing and interlocking provide for fail-safe operation and automatic occurrence of starting and stoping procedures. The beam has a fixed 2° x 40° and can be varied spectrally by inserting filters (on the ground).

1.1 The Illumination Pattern

The radiation source has a 1.5 inch long arc and a reflector system which forms a fan-shaped beam of variable spectral characteristics. It has been found that filters for optimum ultraviolet but minimum visible transmission also permit a significant degree of infrared transmission. Thus, the filters provide both ultraviolet and infrared while removing over 99.9% of the visually

effective radiation. In addition to demonstration of design point operation with filters, operation with filters removed has permitted a large visible output, estimated as over 0.5 million lumens in the same fan-shaped beam. An alternate set of filters, optimized for infrared transmission with effective removal of both visible and ultraviolet light, is included with the package. The infrared power can be increased by a factor of over 4 over that available with the UV-IR filters if the alternate filters are used.

The reflector system used with the line radiation source forms a beam narrower in the fore-and-aft direction than the originally specifided 4 degrees. Analysis has indicated that a reduction in the spread would be desirable in order to reduce exposure time and image motion. This was achieved without increased size and weight. The reflector has an aperture about 6 inches by 14 inches, and our laboratory tests have indicated that approximately 90% of the light is within a 2-degree spread. The 40-degree pattern is close to the desired uniform illumination on a flat plane.

1.2 Systems

The package uses automatic sequencing elements to reduce the number of operating controls to a minimum while assuring safe operation (or termination of operation in the case of malfunctions). The pilot's control (a small, separate control box) consists of a make-ready switch and indicator, an arc start switch and indicator, and an intensity control. The illumination package measures 30 x 36 x 40 inches and has a complete cover, lifting lugs, and power factor correction condensers. These elements, added to the original specifications, have

increased the weight slightly over the 400-pound goal to 470 pounds. The system, as originally specified, weighs 402 pounds.

The radiation is generated in an arc inside a quartz envelope, with flowing argon gas constricting the arc to a narrow column raising its temperature and inducing intense radiation. The argon is supplied from a cryogenic liquid container. Heaters in the container boil off liquid at the desired rate. The gas is then heated to near room temperature before flowing into the device, being heated by the arc, cooled somewhat in a water exchanger, and then discarded along with the cooling air. A closed-loop water system removes heat from the arc electrodes, the reflector and the arc gas, and then rejects the heat to ambient ram air ingested by a scoop. Power, three-phase, 400-cycle, 120/208 volt, is conditioned by a saturable reactor controlled by the pilot's intensity control, a transformer to increase the voltage and a silicon rectifier stack to convert the alternating current to direct current. By this means, the operating voltage of 300-315 volts can be achieved at the desired current of 70-110 amperes. Because an arc power supply tends to have a relatively low power factor, a modification was requested by AFAL to permit operation from generators of lower capacity than those originally specified. Power factor correction capacitors have been included which reduce the total kva demand to about 43 kva for operating everything in the device (except for a minor amount of 28 volt dc control power).

1.3 Summary and Recommendations

The package has been operated in the laboratory using a blower to simulate ram air for the cooling scoop. Satisfactory operation of the assembled

system has been encountered during many starts and a total of about 5 hours of running. Equally reliable operation is expected after installation in an aircraft.

Since the amount of air needed varies little with altitude and depends only on the heat to be rejected while the air actually ingested by a scoop of fixed design varies significantly with altitude and velocity, the rejection of heat to ambient air requires close integration with aircraft performance. For this reason, the source is suitable only for certain altitudes and velocities with the scoop supplied. A more flexible scoop or a scoop designed for a specific aircraft would be needed to cover a wide range of operating conditions.

A desirable change for potential, improved models would be to have a closed-cycle gas system rather than open-cycle. At the time the work was initiated, an open-cycle system was the most assured of success and was weight-competitive. Since that time, development work has shown a good probability of obtaining a satisfactory diaphragm recirculation compressor which would permit indefinite running times as well as operation with gases like krypton or xenon which are more effective in generating infrared and visible radiation than is argon.

Information generated from the course of the work shows significant growth potential for this approach in power, efficiency and performance. Use of reflectors to provide different shape beams, such as 40° square or 45° cone, could be cone with relatively simple changes to result in expanded areas of application.

2.0 35 kw RADIATION SOURCE

The function of the 35 kw radiation source is to establish a small

diameter, long, intensely radiating, electric arc between two non-consumable electrodes. Since the arc is cooled by flowing gas, maintaining a specified current results in a high current density and high temperature core. The combination of high current density and high temperature produces intense radiant energy.

2.1 General Description

The radiation source is shown schematically in Figure 2. The source is composed of two electrodes aligned axially within a pair of cylindrical quartz envelopes. The quartz envelopes are also concentric and axially aligned. The quartz envelopes transmit the radiation and provide pressurization and containment for the swirling flow which constricts and maintains the line arc.

The anode electrode is hollow allowing the gas to exit after it has passed through the arc column. The arc terminates on the interior of and rotates about the circumference of the hollow electrode. The cathode electrode assembly is a movable, recessed stick. The arc attaches to the tip of the stick which is recessed in a tungsten shroud. Because of electron emission cooling, the stick is capable of operating for extended periods as the arc termination point. The cathode assembly has a built-in gas piston so that the stick electrode may be advanced across the 1.5" arc gap to contact the anode and withdraw the arc. The gas supply for the starter piston is the same as that for the arc chamber. Withdrawal of the piston is automatically controlled by a current-sensitive relay which senses the initiation of the arc.

The anode and cathode bodies are axially positioned by the end walls

of the optical system which serve as mounting fixtures for the arc source. The envelope seals are O-rings at each end of the quartz envelopes. The inner envelope is sealed on the I. D., and the outer envelope is sealed on the O. D. The electrode assemblies are cylindrical and fit into the bodies which provide alignment and fluid flow passages.

The arc gas passes through the annulus between the two quartz envelopes, enters the anode electrode assembly, is injected into the arc chamber as a swirling flow, exits the arc chamber after having passed through the arc, and passes through a heat exchanger to be cooled to less than 500°F before being dumped overboard.

All the seals of major components are of the O-ring type to facilitate assembly and disassembly. Thus, the electrodes and quartz envelopes are readily accessible for inspection.

2.2 Range of Performance

The design goal was to produce a radiation source capable of operating at variable input power so that the radiation in the 2400 Å to 4000 Å range could be varied by a factor of 2. The most readily controlled variable in the radiation source is the current at which the source is operated. With fixed flow and geometry, the current defines the chamber pressure and the operating voltage for the radiation source. It is of interest to note that the efficiency with which the radiation source converts electrical energy into radiant energy increases as the current to the radiation source increases. Consequently, to obtain a factor of 2 variation in radiant output requires less than a factor of 2 variation in operating

current. To obtain the desired variation in radiation output, the current to the radiation source is controlled by a saturable core reactor over a range from 72 to 110 amperes dc.

Figures 3 and 4 show spectra obtained at the minimum and maximum operating conditions. The minimum operating condition corresponds to a gas flow of 550 scfh of argon yielding a chamber pressure of 300 psig at a current of 70 amperes and a voltage of 315 volts with a conversion efficiency of 27%. The maximum operating condition corresponds to a gas flow of 550 scfh of argon yielding a chamber pressure of 310 psig at a current of 110 amperes and a voltage of 310 volts with a conversion efficiency of 30%. The stated flows, pressures, voltages, and efficiencies are average values.

It can be noted for the spectral distributions that 8.6% of the radiated energy is between 2600 Å and 4000 Å, 34.6% from 4000 Å to 7000 Å, 31.8% from 7000 Å to 9000 Å and the remaining 25% between 9000 Å and 25,000 Å. Corresponding to each unfiltered spectrum is a spectrum obtained with the radiation passed through a Corning 7-54 filter which is used to tailor the spectral output from the radiation source. In the ultraviolet region from 2400 Å to 4000 Å, the 7-54 filter passes approximately 67.5% of the incident radiation, and in the range from 7000 Å to 9000 Å the filter passes 22.5% of the incident radiation. These spectral ranges are useful for ultraviolet- or infrared-sensitive films.

These spectral distributions are also useful to determine the portion of the visible radiant energy, defined as the 4000 Å to 7000 Å region, which is removed. It can be noted that the 7-54 filter passes 1.5% of the incident radiation

in this region. This radiation is passed at the extreme ends of this spectral region; some passes from 4000 Å to 4400 Å and the rest passes from 6800 Å to 7000 Å. These spectral regions represent extremely non-sensitive portions of a human eye's spectral response. As a result, the transmitted radiation, given in terms of luminosity, has a luminosity of 0.02% of the unfiltered luminosity, meaning that more than 99.9% of the luminous output of the arc radiation is removed by the 7-54 filter.

2.3 Assembly Procedure

The assembly of the radiation source can be divided into two parts which will be described separately: the anode electrode assembly and the cathode electrode assembly.

2.3.1 Anode Electrode Assembly

The anode electrode assembly, shown in Figure 5, consists of several major components: the anode body which contains the fluid passages and is used to align the source in the optics' structural mount, a gas-to-liquid heat exchanger and fitting flange assembly, an electrode nut, a water divider, a gas manifold and an electrode. The assembly procedure (see Figure 6) is most easily started with the gas manifold. Install the front O-ring with the O-ring inserter provided. Insert the water divider into the gas manifold from the rear. Insert the electrode from the front with the electrode flange projecting into the angular front O-ring slot of the gas manifold. The electrode nut can then be screwed onto the electrode and tightened to hold the entire electrode assembly together. Initiate the tightening process by hand, tightening the nut so that the

electrode touches the front O-ring. Then further tighten the nut one-third turn. This is adequate to seal the fluids and allows for differential expansion of the metal parts when the source is operated at high temperatures. Tools are provided for holding the electrode and turning the electrode nut. Once this assembly has been completed, O-rings can be inserted on the gas manifold, water divider and electrode nut circumferences. Then insert this assembly into the aluminum body. Once this has been done, the O-rings can be installed on the heat exchanger assembly. Insert this assembly into the aluminum body to complete the assembly of the primary anode components. The anode electrode assembly can be attached to the optical system and held in place by the four bolts shown with this assembly.

2.3.2 Cathode Electrode Assembly

The primary components of the cathode assembly shown in Figure 7 are the cathode body, the gas manifold, the piston cylinder wall, the electrode housing, the electrode and flow tube, the stop nut, the spring, the gas piston, and the fitting flange. The first step (see Figure 8) in assembling the cathode is to install all the O-rings. Screw the electrode and flow tube together and insert this assembly into the electrode housing. Then insert the resulting assembly into the gas manifold. Position the stop nut over the tubular section of the electrode housing and tighten the set screws. Position the spring at the back of the stop nut and push the gas piston over the flow tube to compress the spring. The compression should be adjusted so that the electrode extends out of the electrode housing 0.2" when the piston is in the forwardmost position. Once this adjustment has been made, lock the gas piston into place by the four set

screws. Then place the piston cylinder wall over the gas piston. This assembly can then be inserted in the insulator. The last component to be assembled is the fitting flange. Slide it over the flow tube and insert it into the rear of the insulator. The cathode electrode assembly can be attached to the optical system and held in place by the four bolts shown.

2.3.3 Maintenance

Little maintenance of the radiation source should be required. In the anode electrode assembly, the only component which can deteriorate is the electrode. This can be determined by looking at the external electrode surface, or by removing the electrode from the assembly. It is important that if the electrode is replaced, the O-rings associated with the electrode also be replaced.

The electrode is the most likely part of the cathode assembly to deteriorate. If this electrode is replaced, the entire electrode and flow tube assembly should be replaced by disassembling the electrode assembly.

It should also be noted that since the cathode electrode assembly is designed to move during starting, it is necessary that the piston O-rings have lubrication. It is also important that the lubrication be applied with restraint so that it does not get into the gas stream and contaminate the quartz envelopes. A silicone O-ring grease, such as Stopcock grease by Dow-Corning, is recommended. The need for lubrication of this piston assembly will be indicated by sluggishness of the piston action during the starting process.

It might also be noted that, as is true for all O-ring seal devices, the O-rings have a finite life and are subject to accelerated deterioration

at high temperature. Consequently, if the source is to be stored for a long period (greater than 2 months), it would be advisable to replace the O-rings prior to renewed use to avoid possible leaks.

Maintenance will be required infrequently; but when necessary, the procedures outlined in the foregoing paragraphs should be followed exactly, and great emphasis should be placed upon care and cleanliness.

3.0 OPTICAL SYSTEM

The primary purpose of the optical system is to produce a narrow fan of radiation so as to illuminate a narrow rectangular pattern at some distance from the optical system. The fan is determined by two angles of divergence which give the beam divergence in two planes oriented perpendicular to each other from a common point (the exit opening of the optical system). The narrow beam divergence angle (in the flight direction) is specified to be 4° or less. The wide divergence beam angle (transverse to the flight direction) is specified to be 40°. The size of the illumination pattern is determined by the distance of the illuminated area from the exit plane of the optical system.

In addition to the required angular coverage, it is necessary that the illumination be more intense at the periphery of the rectangular pattern so as to account for the cosine^4 fall-off with a camera lens. This requires that the illumination on the ground be more intense at the edges by the sec^4 of the lateral half-angle. The optical system has been designed to direct radiation more strongly toward the periphery so that the entire film plane will have a uniform density to provide high contrast and resolution over the ground area.

A 2° x 40° optical system has been designed for the prototype. The 40° divergence is considered adequate to provide the maximum angular coverage for a single lens of reasonable f-number. Although a 4° divergence was specified as the upper limit for the beam divergence, measurements of the prototype illumination pattern have indicated that 80% to 90% of the radiation is with a 2° beam. The 2° beam spread is more desirable than the 4° beam for minimizing film blurring and image motion compensation requirements.

3.1 General Description of Reflective and Absorptive Elements

The reflective optical system components shown schematically in Figure 9 can best be described by listing some of the pertinent general features:

1. The optical system makes extensive use of cylindrical reflector optical elements. The cylindrical elements are utilized to complement the long line cylindrical arc source.

2. A cylindrical mirror concentric with the axis of the arc column is used to return radiation through the optically thin arc to the primary optical surfaces.

3. Optical surface elements which would normally be blocked by the arc and the concentric mirror accompanying the arc are positioned in such a way as to direct radiation past the arc, allowing the radiation to exit the optical system in an area that is free from blockage. These blockage-eliminating optical surfaces are designed to yield a theoretical 100% utilization of the arc radiation in the plane perpendicular to the arc axis.

4. To obtain the small divergence beam, cylindrically parabolic

optics are used with the axis of the arc column being at the focal point of the cylindrical parabola. The maximum divergence angle of the exiting light beam is determined by the angle subtended by the arc diameter at the primary focal length of the optical system. It should also be noted that cylindrically parabolic surfaces can be approximated over short segments by circularly cylindrical elements, and this has been done in various parts of the optical system.

5. End walls used with the cylindrically parabolic surfaces are flat and perpendicular to the axis of the arc column and the cylindrical optics from the arc axis to the apex of the optics. Contoured end walls, used to control the beam divergence in a direction transverse to the narrow beam direction, are used from the arc axis to the optics aperture. The contoured end walls are located between the arc axis and the optics opening so that the radiation striking these end walls has already been focused by the parabolic surfaces and is "in the beam" in the narrow divergence plane.

6. Beam spreaders are small, flat mirrors located at the opening of the optical system. There are two such flats located at the outer edges of the parabola opening to take exiting radiation which has already been put into the narrow beam and redirect it into the wide beam direction.

In addition to directing the radiation into the desired beam with the prescribed distribution, it has also been required that the radiation be spectrally tailored to eliminate the visible portion of the spectrum, allowing only the ultraviolet and infrared radiation to exit the optics. Two filtering elements shown schematically in Figure 9 are used to remove unwanted radiation:

1. Dichroic or interference filters are used at the wings of the optical system to remove unwanted radiation by allowing it to pass through the quartz elements on which dichroic is coated and be absorbed by blackbody absorbers located behind the elements. Only the ultraviolet radiation is reflected from these elements.

2. Numerous absorption filters located in the optics exit aperture are used to remove unwanted radiation by absorbing the energy within the filter material. The absorbed energy is removed by air cooling of the filter elements.

The initial concept called for utilizing commercially available Corning 7-54 filters to remove the 4000 Å to 7000 Å visible radiation allowing the ultraviolet and infrared portions of the spectrum to be transmitted. The Corning 7-54 filters do remove the required energy as shown in the spectra included with the previous section of this report. Preliminary tests indicated that, at the high energy removal rates of 80 to 100 watts per square inch required with the optical design, the filters would be unable to sustain the associated temperatures and thermal stress conditions. The 7-54 filters are composed of two separate dyes, each removing a portion of the visible spectrum. Two sets of filters were acquired, each removing a different portion of the visible spectrum, so that the loading on each filter could be significantly reduced. In addition, very thin and long filter strips are used to reduce the temperature gradients and associated thermal stresses.

Tests with the optical system have indicated that with sufficient air cooling the filter strips generally survive. Occasionally, the strips crack at maximum

power from the extreme loading and temperature gradients. To remove any possibility of a cracked filter disrupting the coolant air flow and causing destruction of all the surrounding filters resulting in a loss of covertness, metal H-bar grids are used to hold the filters in position even should they crack. Consequently, the optical system strip filters are held on all sides by grooves so that any broken filters will remain properly oriented in the system and accomplish the job of filtration until the end of the mission. This arrangement assures that breaking of the filters will represent only an occasional operational cost, but will in no way hinder proper operation of the filter system.

During the testing phase of the program, the optical system was assembled element by element and the durability of each element evaluated. The metallic reflective elements are capable of sustaining the radiant loads using the prescribed cooling. The wing dichroic filter elements are capable of sustaining the loading associated with removing the unwanted radiation. The assembled optical system has been operated in the laboratory for more than five hours at power levels ranging from 20 to 35 kw and has been shown capable of providing the required filtering and beam control.

3.2 Evaluation of the Beam Pattern

Determination of the narrow beam divergence has shown the beam to have a maximum divergence of 2.3° as determined by viewing backwards into the optical system until all the elements become inactive. This implies that 80% to 90% power point in the beam is considerably less than 2.3°, most likely being of the order of 2°.

A prototype optical system using a 500-watt, quartz-iodine lamp was constructed prior to building the actual system, and was used to determine the beam control to be accomplished in the 40° direction. Figure 10 shows the illumination on a flat area achieved with the prototype. At the ± 20° points, the illumination drops to 52% of the peak value. Allowing the illumination to drop off at the edges greatly reduces spillage outside the ± 20° limits.

The total power output from the optical system has not been quantitatively determined, but indications are that the optical system directivity efficiency is in the range of 60% to 70%. This value has been partially confirmed by measurement of the heat absorbed in the optical system elements. Some energy tends to be conducted and reradiated away from the optical system so that any heat balance determination is not totally accurate. In addition to the power lost outside the desired beam or absorbed by the optical surfaces, considerable energy is removed in the filtering process. Only about 15% of the energy that would exit the optical system and be in the beam if it were used in the visible mode passes through the filters. This yields a total output in the beam of less than 900 watts divided between the ultraviolet and infrared spectral regions. It might also be noted that by using the wing dichroics which reflect only light in the ultraviolet region, some of the infrared energy is removed. The wing dichroics handle 24.4% of the radiant energy emitted by the arc so that the IR is reduced to 75.6% of that available if the absorption filters were utilized alone.

Typical calculated values of the available beam power with the dichroic and absorption filters in place are listed as follows for several wavelength regions

of interest:

3400 - 4000 Å	260 watts at max. power
3400 - 4000 Å	140 watts at min. power
7000 - 9000 Å	360 watts at max. power
7000 - 9000 Å	230 watts at min. power

3.3 Assembly and Installation Procedure for Optical System

The primary structural components of the optical system shown in Figure 11 are the two mirrored end walls which are positioned and held by an aluminum cross-member (saddle). This saddle provides structural strength alignment and mounting for the concentric mirror. Once the two end walls and saddle have been assembled, the concentric mirror can be placed in position and bolted down.

The next step is installation of the arc source. Insert the cathode electrode assembly previously described into the positioning hole on either side of the optical system and screw the bolts into the tapped holes in the end wall of the optical system. The quartz envelopes can then be assembled. The <u>only</u> lubricant to be used for the O-rings sealing the quartz envelopes is distilled water, and this should be used in moderation. Insert the quartz envelopes through the optical system from the side opposite the cathode assembly. Then insert the anode assembly into the quartz tubes with the optical system support hole providing alignment. Push the anode assembly forward while rotating clockwise. Once the anode assembly has advanced until the optical system stops further forward motion, the

assembly is complete. The anode assembly can then be bolted into place. In order that the distilled water not be spread over the interior of the quartz envelopes by the gas, vacuum pump through the source heat exchanger while sealing the gas inlet and pressure tap until the water is evaporated. This completes assembly of the source into the optical system.

Once the source is in place, the two saddle mirrors at the top of the optical system can be attached. Then install the parabolic mirrors which are held in place on the optical system by the trellis networks. Use heat sink compound between the cooled trellis networks and the parabolic surfaces to assure good thermal contact. Then install the two 23-degree dichroic mirrors and two 18-degree beam splitter mirrors on either end as shown.

Grooved guides are used to hold the filters in the optical system. Position the filter guides in the mirrored end walls as shown and insert the filters from each end. An aluminum H-beam which acts to support the edge of the filters is used between each filter. Seven filters must be inserted into each of three layers on either side of the saddle support. The light yellow colored filters must be positioned closest to the source, then the blue colored filters and the darkest-colored filters nearest the outside, as shown in Figure 9.

In the reflector, the water flows through three parallel loops which are all interconnected. The first loop goes through the sidewall, into the saddle, through the concentric mirror, out the saddle, and through the sidewall. The other two loops start at the saddle mirrors, go through the trellis networks and then go through the absorbers for the dichroic elements.

Air cooling is provided for the filter network. Fittings on either side of the optics provide attachment for 2" diameter, flexible hoses. These hoses take air from the scoop and thrust the air into the optical system so that it may move along the surfaces of the filters to provide cooling. After the optical system is mounted in the package on the four shock mount points, the 2" diameter air ducts, water coolant loops for the source and optics, and power cables should be attached. This completes installation of the illumination source-reflector assembly.

3.4 Maintenance

The primary maintenance requirement for the optical system is cleanliness, It is important that the optical surfaces remain free of water, dust, oil and other contaminants. The reflector surfaces can be cleaned with a window cleaner such as Windex and a soft cloth.

The absorption filters require special attention since they are quite delicate and easily broken. After hours of operation, it is likely that some of the filters will be cracked. Although this does not affect the operation of the illumination system, once disassembled, the broken filters cannot be readily reassembled. This means that new filters should be installed to replace the cracked filters after every complete disassembly.

The quartz envelopes, should they become contaminated, will require cleaning. The most advisable procedure is to remove the two saddle mirrors so as to provide visual access. Unbolting either electrode assembly allows the envelopes to be removed from that end of the optical system. There is provided

a separate structural mount into which source ends can be inserted once they are both removed from the optics so as to enable holding the envelopes to pull them off the O-rings which tend to become vulcanized from the high temperature. The source should be reassembled into the optical system as previously described and the two saddle mirrors replaced. Removing the saddle mirrors also provides a rapid visual check on the condition of the quartz envelopes after extended operation.

4.0 AUXILIARY SYSTEMS

4.1 Power Supply

The radiation source system requires an external supply of 400 cps, 208 v, 3-phase, alternating current. The input kva requirement versus radiation source input power is shown in Figure 12. Approximately 3.5 amperes of 28 v dc power are required. The location of the power input connections is shown in Figure 1.

The illumination system power supply elements include a main contactor consisting of a power relay in each phase, a saturable core reactor, a transformer, a rectifier and capacitors for power factor correction, as shown in Figure 13. The power supply circuitry is shown schematically in Figure 14. Three power relays within the main power distribution box switch power to the reactor/transformer automatically upon signal from the control system. dc current is supplied to the reactor control winding from a dc control circuit located in the pilot's control box. After rectification, power having the dc volt-ampere characteristic shown in the insert of Figure 14 is delivered to the arc electrodes.

4.2 Control System

The function of the control system is to operate the system safely with minimum demand upon the operator's attention. The control system of the airborne light source regulates the distribution of electrical power to the auxiliary systems and the arc power supply. The control system initiates the functions required before the arc starts and monitors the operation of the auxiliary systems during arc operation. The starting point of the control system is the pilot's control box. As shown in Figure 15, the manual operations required of the pilot are few. The "ready switch" prepares the auxiliary systems for operation of the light source. The "arc on switch" turns on the light source. Two signal lights indicate the "ready" or "on" status of the 35 kw illumination system. The "intensity control" provides means for presetting or adjusting the intensity of the light output. Figure 16 diagrams the control functions which automatically result from actions taken by the pilot. Elements in the control system are detailed in Figures 14, 17 and 18.

4.3 Gas Delivery System

The gas delivery system shown in Figure 19 comprises a liquid argon storage vessel and heaters for vaporizing the argon at a controlled rate. A flow schematic of the gas delivery system is included in Figure 20. The storage vessle is a vacuum-insulated, spherical container which holds 22 liters (approximately 67 pounds) of liquid argon. Immersion heaters inside the vessel vaporize argon to raise the internal pressure to 500 psig. Pressurization from atmospheric pressure to 500 psig requires approximately 8 minutes' operation of the immersion

heaters. Additional superheaters are located externally to further warm the argon gas being delivered. The delivery tube is finned to raise the argon gas to ambient temperature before it enters the radiation source. Instructions for filling the argon vessel are included in Section 5.2.

4.4 Coolant System

The airborne radiation source coolant system shown in Figure 21 uses distilled or demineralized water in a recirculating loop to cool the arc electrodes and the optical system. The water in turn is cooled by passing through a liquid-to-air heat exchanger. A ram air scoop directs ambient air through the heat exchanger. The scoop is sized to ingest approximately 170 pounds per minute of ram air at a flight velocity of 150 knots. The scoop is retracted by hydraulic actuators when the radiation source is turned off. The ingested air leaves the compartment via two exhaust ducts located in the floor of the compartment. These exhaust ducts are permanently open.

5.0 SYSTEM PREPARATION PROCEDURE

5.1 Cooling System

5.1.1 Required Equipment:

1) A source of argon gas with regulated pressure up to 50 psig for purging and pressurizing the coolant system.
2) A vacuum pump to evacuate the system before filling with liquid.
3) A coolant system service box, which includes the

necessary valves, connection hoses and pressure-indicating gauge. This is included with the illumination system.

5.1.2 Purging and Filling the Coolant System

Removing the access panel from the top of the system enclosure (see Figure 1) reveals the water fill connection to the coolant system, as shown in Figure 22. This connection is used for purging, system evacuation, filling and pressurizing.

To purge the coolant system with gas, connect the water transfer tube of the coolant system service box shown in Figure 23 to the water fill connection. Then open the coolant fill valve above the water fill connection by turning the handle 90° counterclockwise. Connect argon gas to be used for purging to valve A of the service box. Then open the coolant drain valve (see Figure 24). Introduce gas to the coolant system by opening valve A of the coolant system service box. Do not allow the gas pressure introduced to the system to exceed 20 psig as indicated by the pressure gauge attached to the service box. The gas will purge the system of most of the remaining liquid in 1-2 minutes. After purging, the coolant system must be evacuated to remove trapped air and water vapor in the system. To do this, connect a vacuum pump to valve B of the service box (see Figure 23). With the vacuum pump operating, close valve A, close the coolant drain valve (Figure 24) and open valve B. Allow the vacuum pump to draw the vacuum to 28" Hg or more and remain operating for at least 30 minutes. This will draw all air and water vapor pockets out of the closed system. At the end of

this period, close valve B and turn off the vacuum pump. If the coolant system is leak-tight, the vacuum will not decrease and the system is ready for filling. Disconnet the vacuum tube from valve B.

Connect the transfer tube from a distilled water container (Figure 23) to valve B and open valve B. The vacuum will draw approximately three quarts of water into the system. Disconnect the transfer tube from valve B, leaving the valve open. Next, to assure proper liquid level in the system, open the coolant overflow valve (Figure 24). Water will drain from this valve until the proper level is reached. Close the overflow valve, close valve B and the system is properly filled.

5.1.3 Coolant System Pressurization

With argon gas connected to valve A of the coolant system service box (Figure 23), raise the gas pressure to 11 psig. Then open valve A allowing the gas to enter and pressurize the coolant system to 11 psig. Close valve B. Read the proper pressur on service box gauge. Close the coolant fill valve (Figure 22) and disconnect the transfer tube from the water fill connection. The coolant system is now filled, pressurized and ready to operate. It need not be refilled unless pressurization is lost or coolant line is disconnected, allowing trapped air into the system. System pressurization may be checked periodically by attaching the service box to the fill port, opening the coolant fill valve and reading system pressure on the service box gauge.

5.2 Gas Supply System

5.2.1 Filling the Liquid Argon Vessel

The liquid argon fill connection to the liquid argon vessel

is located under the access panel shown in Figure 1. Removing this panel reveals the liquid argon fill connection and the converter vent valve as shown in Figure 22. Open the vent valve to atmosphere by turning its handle 90° counterclockwise. If the vessel is pressurized at the time, gas will vent through the right side exhaust duct shown in Figure 24. Attach the fill line to the gas fill connection after removing its protective cap. Begin filling and continue until the vent line begins to vent liquid argon at a constant rate from the right side exhaust duct. This indicates that the vessel is filled to the proper level (approximately 22 liters). Close the vent valve. Disconnect the fill line from the fill connection. Replace the protective cap.

5.2.2 Check of Internal Temperature

The gas temperature inside the liquid argon vessel is used as a control signal to indicate when the vessel is empty of liquid. The internal temperature is indirectly indicated on the gas thermometer pressure gauge shown in Figure 22. After filling the vessel with liquid argon, this pressure should be checked. The proper reading is 15 psig $\pm$ 1.0 psig. If the reading is outside this range, it should be adjusted. Adjustment is made with the method used to pressurize the coolant system (see section 5.1.3). Connect the argon line to the gas thermometer port shown in Figure 22. Open the gas thermometer valve and adjust the pressure to the proper reading.

5.2.3 Electrical and Control Systems

Preparing the electrical and control systems for operation involves connecting electrical power to the proper input terminals and connecting

the control box cable to its receptacle. Figure 1 shows the locations of these terminals. Three-phase, 400-cycle ac power should be connected in the phase sequence denoted on the terminals. The voltage required is 208 v phase-to-phase (120 v phase-to-neutral). The dc voltage required for internal control equipment is connected to the two terminals designated dc with the proper polarity shown. The required dc voltage is 28 v dc. Power consumption is approximately 120 watts.

5.2.4 Removal of Optical System Shield

The radiation source enclosure incorporates an aluminum panel which slides in to protect the optical system (see Figure 24). This shield is marked "Remove Before Operating". This must be observed or severe damage to the optical system will result.

6.0 OPERATING PROCEDURE - AIRBORNE OPERATION

The following procedure relates directly to operation in a forward moving aircraft. For static operation either aloft or at ground level, an auxiliary source of forced cooling air must be supplied to the air scoop. This air requirement is 2600 cfm at a static pressure (gauge) of 14" of water. This pressure corresponds to ram pressure in sea level flight at 150 knots.

6.1 Starting Sequence

All operational control functions originate at the pilot's control box (Figure 15). To initiate the starting sequence, the "ready switch" is first turned on. This begins pressurization of the liquid argon storage vessel and checks that the coolant system and transformer are ready to function. Pressurization of

the gas system requires approximately 8 minutes. When the gas pressure reaches a preset level, the ready light on the control box lights. At this point it is recommended that the "ready switch" be turned off until actual operation is desired if there is to be a delay of more than ten minutes before starting the radiation source. The "ready switch" must be on before the radiation source can be started, however.

Ignition of the radiation source is accomplished by turning on the "arc on switch" shown in Figure 15. This switch triggers a series of automatic start functions which delay the start of the light source by ten seconds.

6.2 Beam Intensity Adjustment

The dial at the top of the control box (Figure 15) controls the intensity of the radiation output. Turning the knob clockwise increases intensity. The desired position of the intensity control when starting the arc is at the minimum stop. The intensity control setting may be changed at any time during operation.

6.3 Intermittent Operation

The radiation source may be operated for short periods intermittently by using the "arc on switch". The system will standby in the ready condition between operating periods. The ten-second delay to start is repeated each time the light source is turned on. Rapid cycling of the on-off switch is not recommended.

6.4 Altitude and Flight Velocity Limitations

The operating altitude and flight velocity limits of the illumination

system are fixed by the requirements of the ram air system. At low velocity and high altitude, insufficient ram air is available for cooling, while at high velocity and low altitude ram drag exceeds the structural design limit of the ram air scoop. The estimated operating envelope is illustrated in Figure 25. This range of operation may, of course, be extended by tailoring the air scoop design to a specified aircraft and mission.

6.5 Operating Time and Shut-Down Procedure

The maximum continuous operating period of the light source system is fixed by the capacity of the liquid argon vessel. With a 22 liter fill, the vessel will supply argon for sixty minutes' operation. At the end of this period, depletion of gas pressure will automatically turn the radiation source off. When this occurs, the "arc on" indicator light on the pilot's control box (Figure 15) will extinguish. As soon as possible after this indication, the pilot should shut down the system auxiliaries by:

1) First turning off the "arc on switch",

2) Then turning off the "ready switch".

This sequence of switching will allow the ram air scoop to close and lock properly.

If the radiation source is to be turned off after less than sixty minutes' operation, the two switches should be turned off in the same sequence as above.

7.0 SECURING SYSTEM AFTER OPERATION

7.1 Replace Optical System Shield

7.2 Vent Unused Argon

If all of the argon has not been used it may be vented so as to depressurize the argon vessel. This is accomplished by gaining access to the gas vent valve (Figure 1) and opening it as described in the filling procedure, Section 5.2.1. This will exhaust the remaining gas through the right side exhaust duct.

7.3 Purge Coolant for Low Temperature Storage of System

If the illumination source system is to remain idle in an enviornment below 32°F, the coolant system should be purged by the procedure given in Section 5.1.2.

8.0 SAFETY CONSIDERATIONS

The illumination system incorporates a high pressure gas system, a source of light intense enough to injure, and voltages high enough to be lethal. Although every effort has been made to make the system fail-safe, the presence of these factors demands prudence and caution in the handling and operation of the equipment. The following precautions are included here in the interest of fostering this prudence.

8.1 Personnel Exposure to the Radiation Beam

Exposure to the radiation should be as brief and as seldom as possible. Direct viewing into the optics aperture should be done only with welding glass of G 14 or greater density and from a distance of 100 feet or greater. Exposture of the skin to the direct radiation beam should be limited to a distance of

at least 100 feet and a time of no more than one minute. Obviously, personnel sensitive to sunlight should not expose themselves to the direct radiation beam. It is suggested that a distance of 10 feet be maintained from the optics aperture for exposure to the diffuse randomly reflected radiation from the beam and that such exposure be limited to five minutes. In general, exposure to/or viewing of the radiation beam should be accorded the same precautions given to viewing the sun on a bright day. It should also be noted that because the visible radiation is mostly removed, there will be a natural tendency to underestimate the harmful ultraviolet energy present. It should always be remembered that it is the invisible ultraviolet that can cause sunburn and serious eye damage.

8.2 Electrical Hazard

All equipment installed in the illumination source package is electrically grounded to the framework. The frame is connected to the neutral terminal of the input power. This terminal should be connected to a local ground to avoid the frame assuming voltage.

Several exposed electrical cables and terminals within the system enclosure acquire lethal potentials during normal operation. For this reason, it is imperative that personnel not work within the system enclosure whenever power is connected.

8.3 Liquid Argon Handling and Pressure Vessel Precautions

Servicing the liquid argon vessel requires the normal precautions in handling cryogenic liquids. Cryogenic liquids produce an effect on the skin similar to a burn. The very cold gas issuing from the liquid can also produce

these "burns". Delicate tissues, such as thos of the eyes, can be damaged by an exposure to the cold gas which may be too brief to affect the skin of the hands or face. No unprotected part of the body should be allowed to touch uninsulated tubes containing liquid argon. The extremely cold metal may stick to the flesh and tear it when withdrawn. Loose fitting leather or asbestos gloves and a shield or safety goggles should be worn.

The argon pressure vessel becomes pressurized to 500 psig for operation of the radiation source. Once the vessel has been filled and the vent valve closed, the small heat leak from its surroundings will gradually build up the internal pressure by evaporation of some liquid. For these reasons, whenever the vessel contains some liquid and is not vented to atmosphere, it should be regarded as being pressurized.

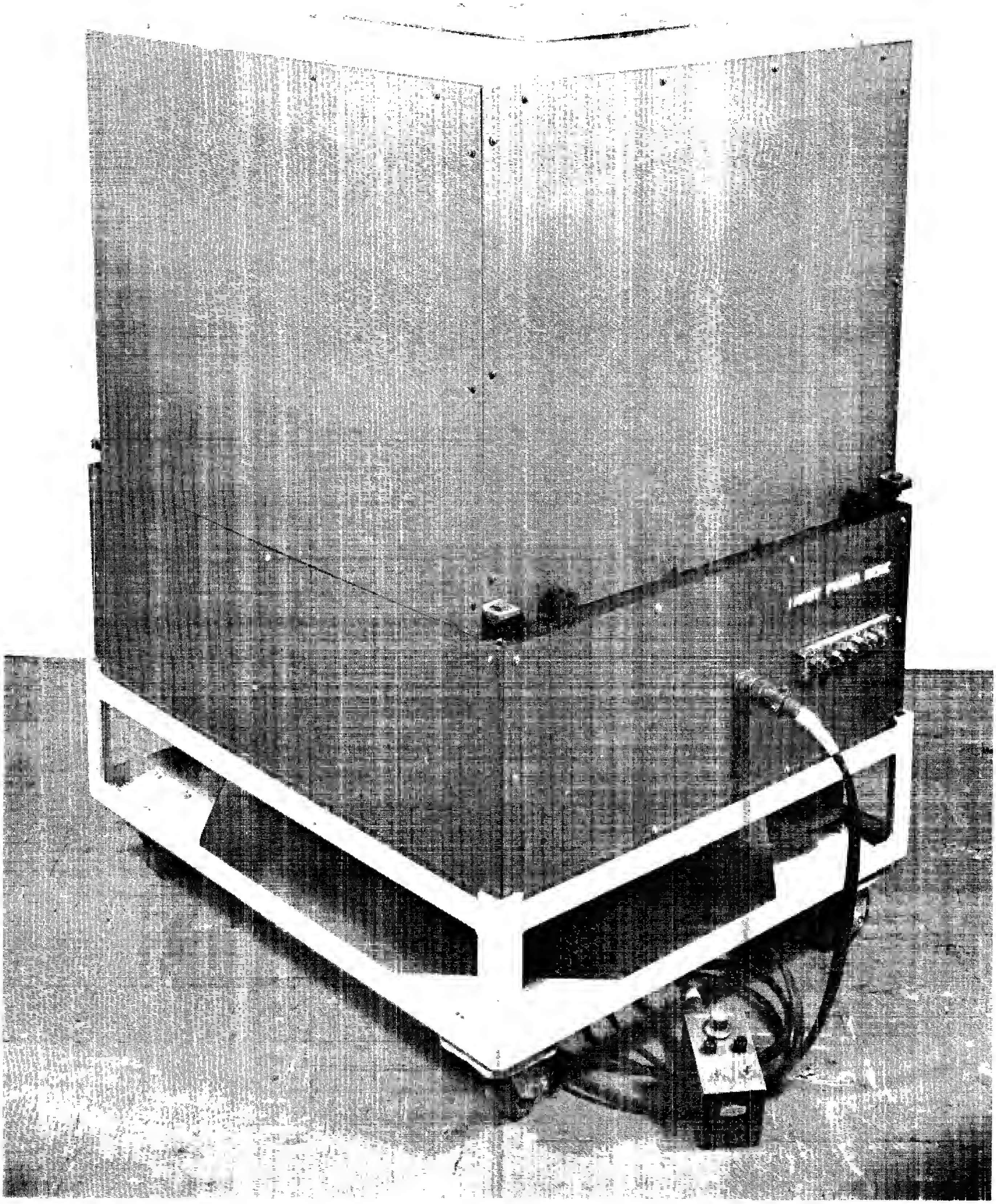

FIGURE 1 35 kw Illumination System and Pilot's Control Box

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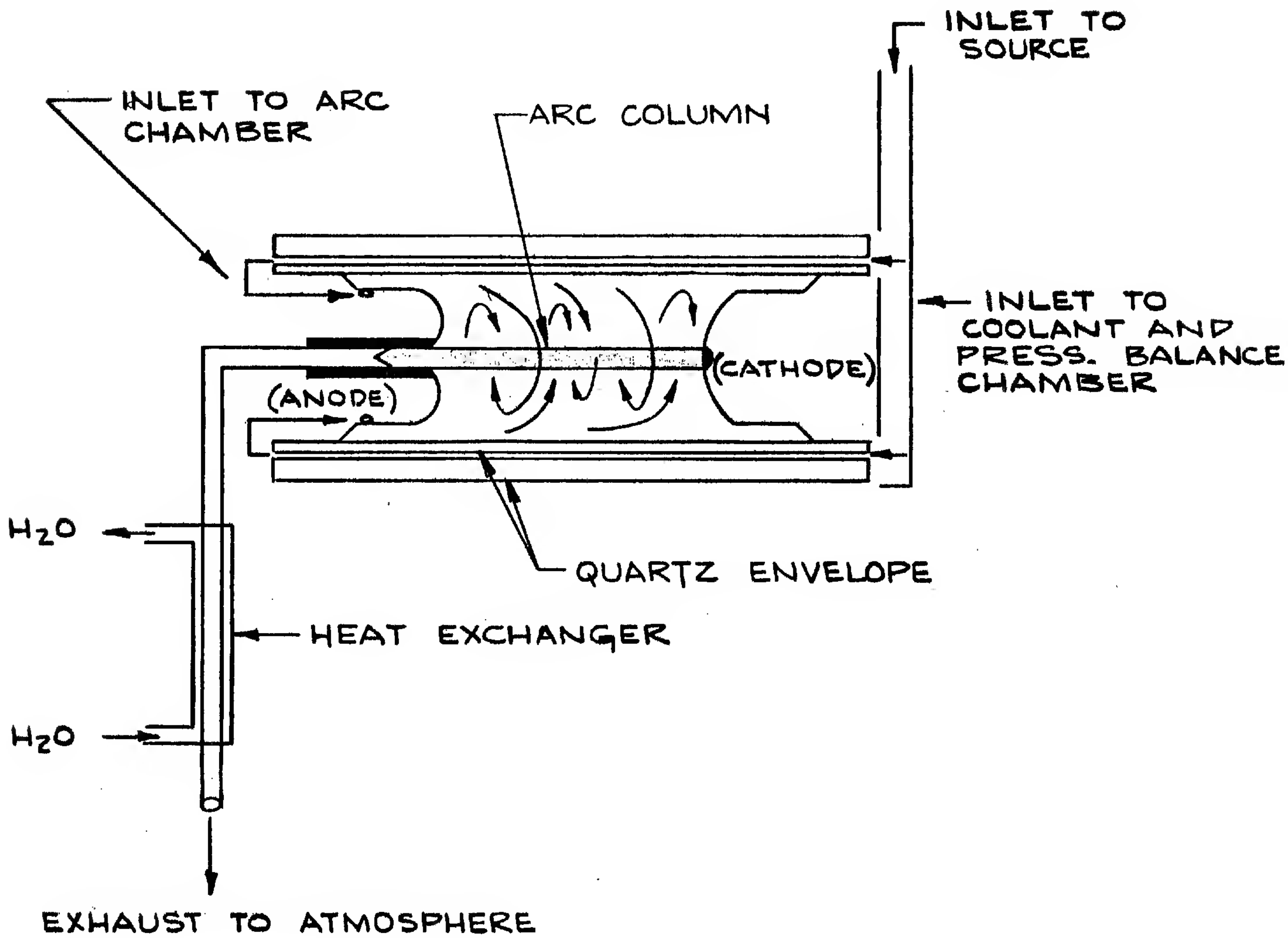

FIGURE 2 Schematic of 35 kw Radiation Source

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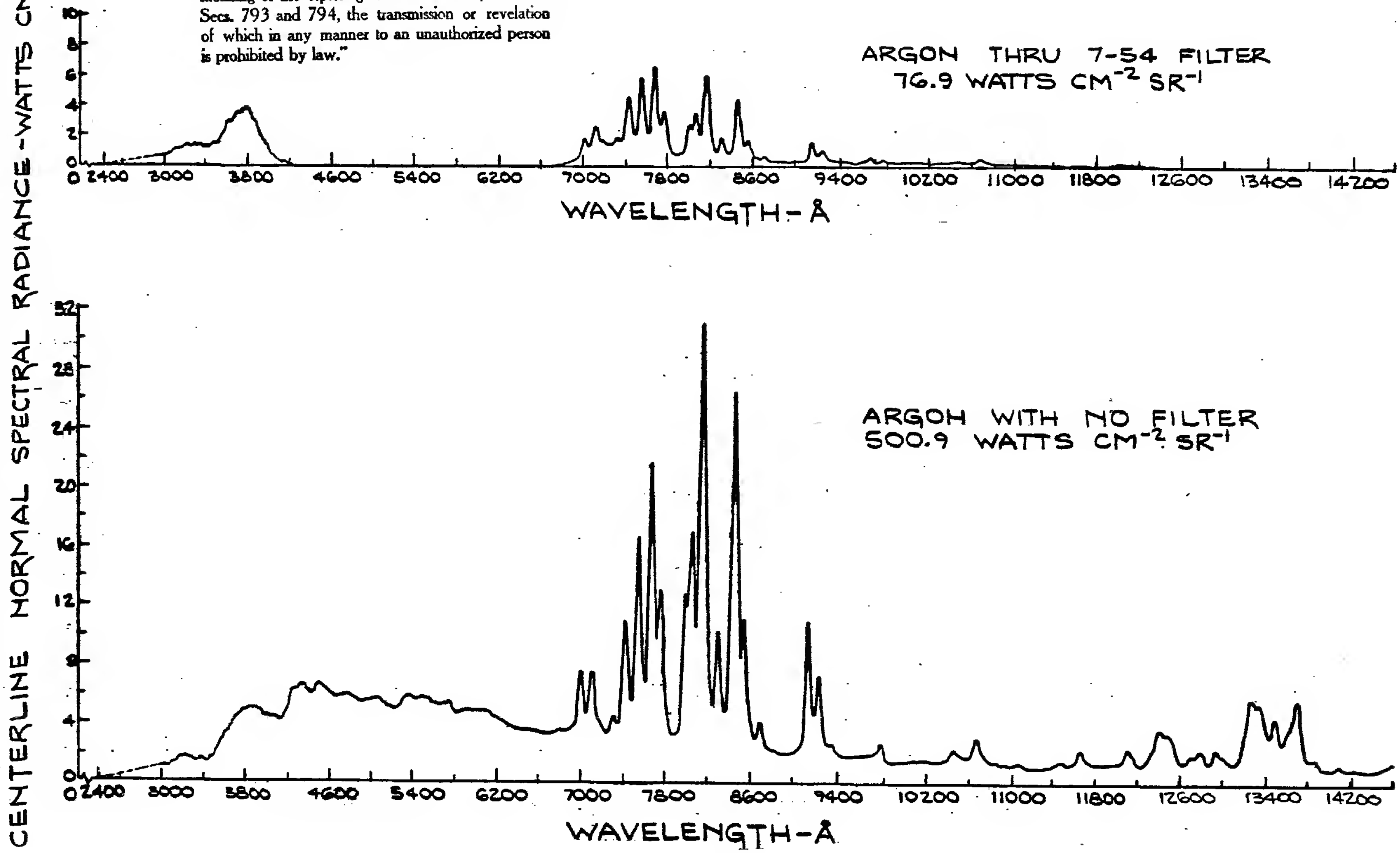

FIGURE 3 Radiation Spectra at Minimum System Output

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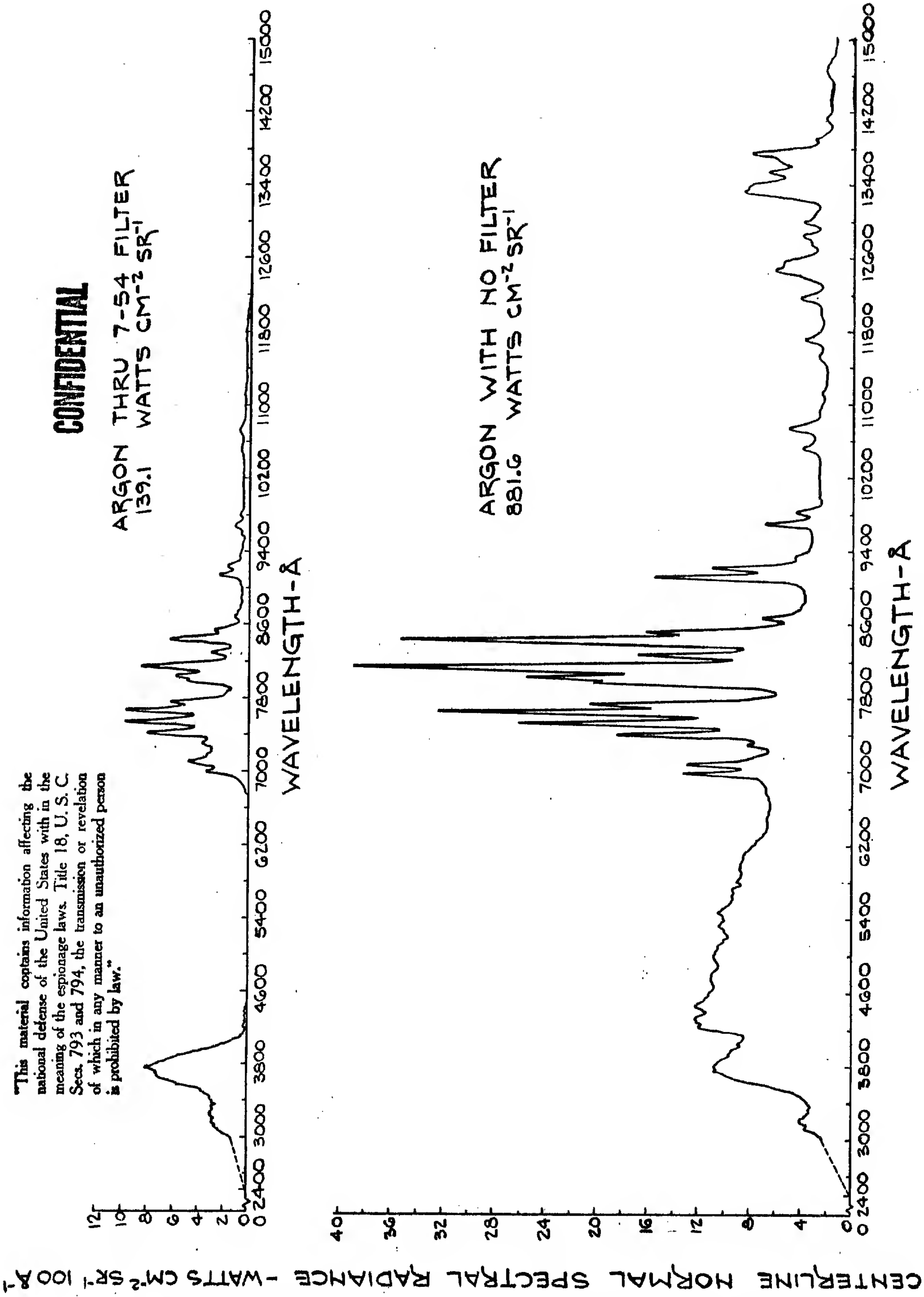

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FIGURE 4 Radiation Spectra at Maximum System Output

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1. Gas-to-liquid heat exchanger. (P.N. BM-20831)
2. Anode fitting flange assembly. (P.N. B-20846)
3. Electrode nut, water divider, gas manifold, and electrode assembly.
4. Anode body. (P.N. B-20837)

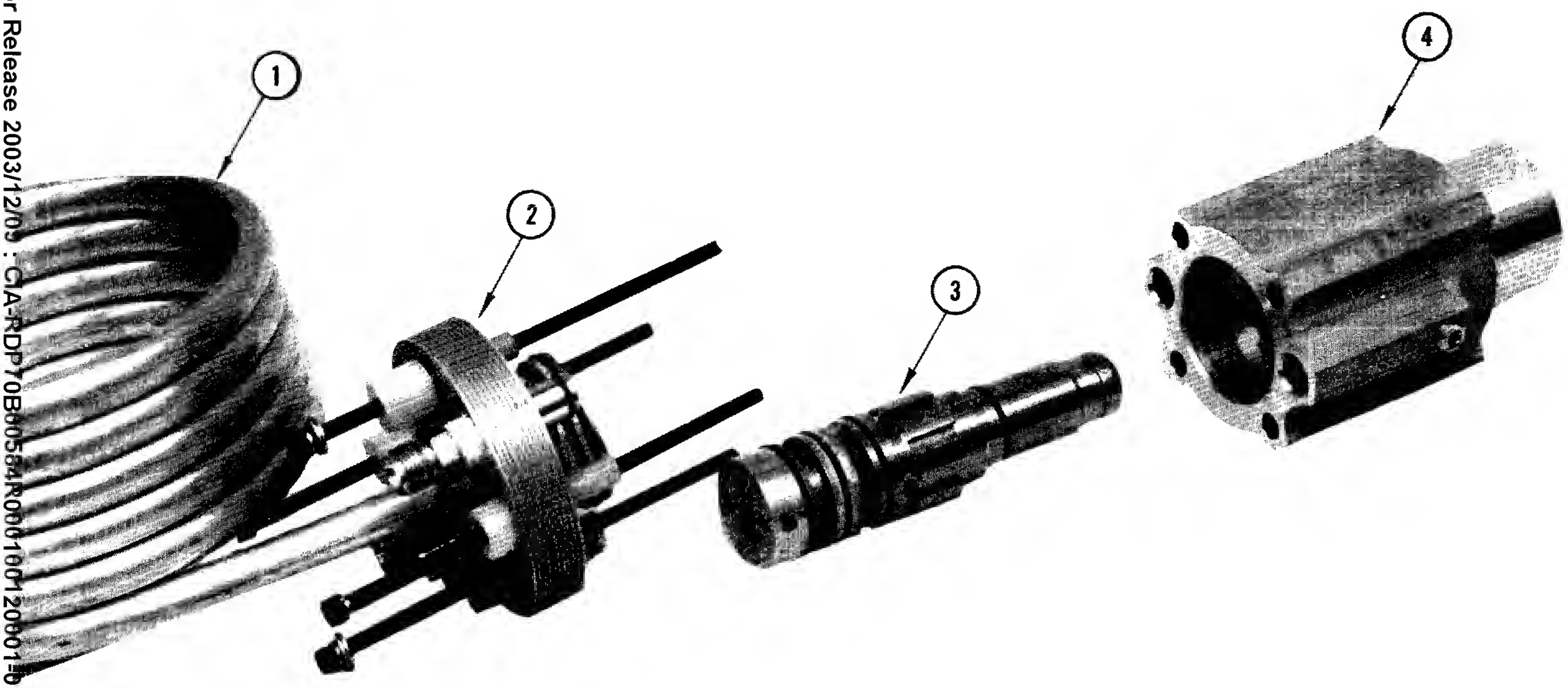

FIGURE 5 Anode Electrode Assembly for 35 kw Radiation Source

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1. Electrode nut. (P. N. C-29836)
2. Water divider. (P. N. C-20834)
3. Anode gas manifold. (P. N. C-20833)
4. Electrode. (P. N. C-20832)

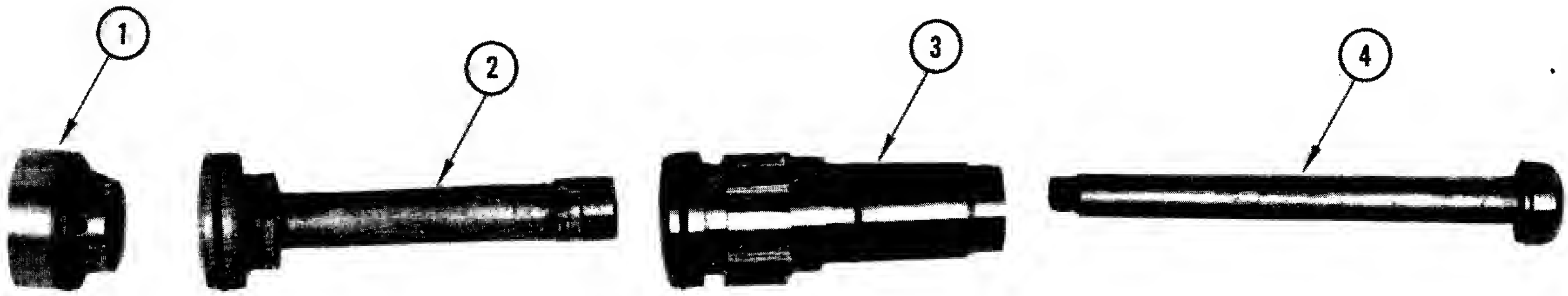

FIGURE 6 Anode Electrode Subassembly for 35 kw Radiation Source

1. Cathode body. (P.N. B-20828)
2. Cathode electrode subassembly. (Ref. Figure 8)

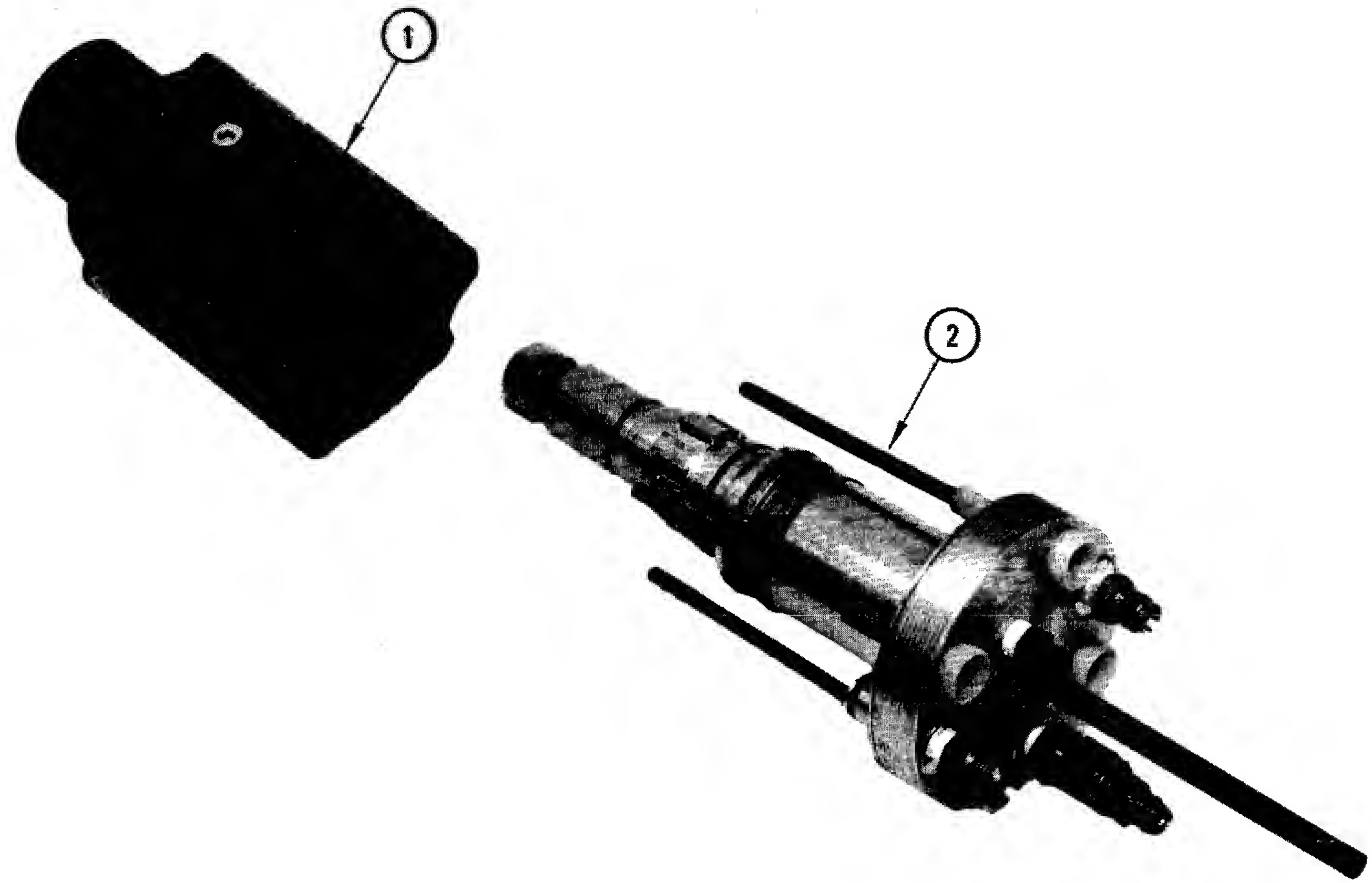

FIGURE 7 Cathode Electrode Assembly for 35 kw Radiation Source

1. Gas piston. (P.N. D-20823)
2. Spring. (P.N. BM-20829)
3. Stop nut. (P.N. D-20863)
4. Flow tube. (P.N. C-20864)
5. Electrode. (P.N. D-20862)
6. Cathode gas manifold. (P.N. C-20830)
7. Electrode housing. (P.N. 20822)
8. Cathode fitting flange assembly. (P.N. C-20827)
9. Piston cylinder wall. (P.N. C-20826)
10. Cathode body. (P.N. B-20828)

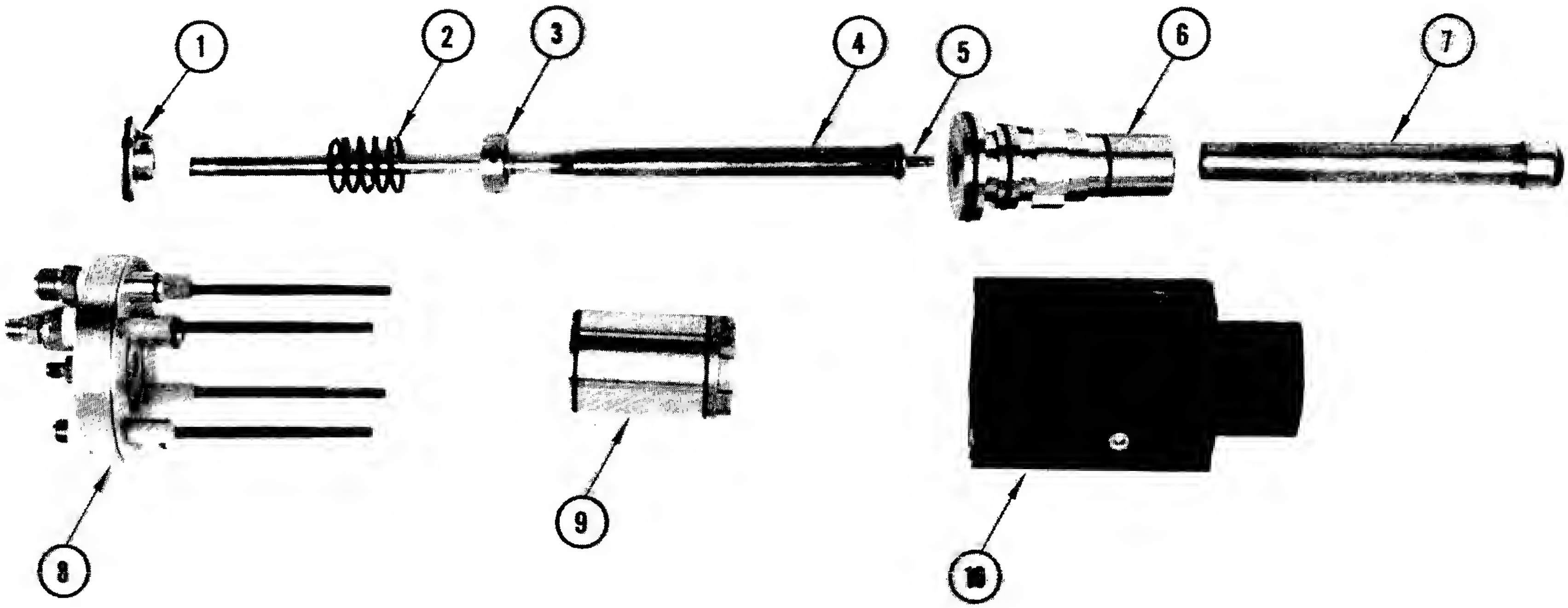

FIGURE 8 Cathode Electrode Subassembly for 35 kw Radiation Source

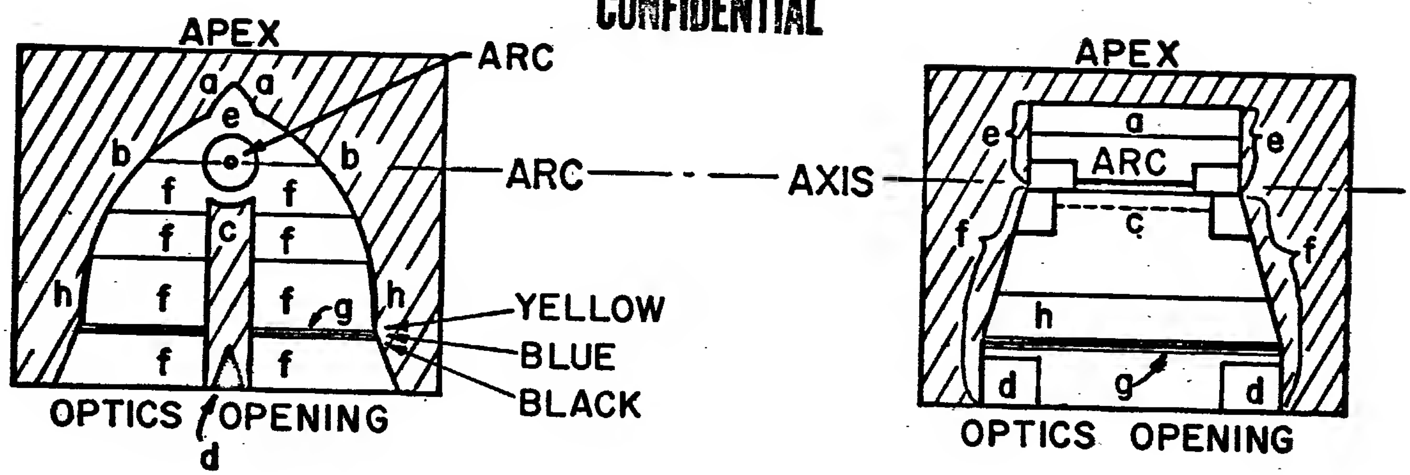

FIGURE 9 Schematic of Reflective-Absorptive Optical System for 35 kw Illumination System

a. Cylindrical parabolic segments.
b. Major cylindrical parabolic segments.
c. Cylindrical concentric mirror.
d. Beam-splitter mirrors.
e. Optical flat end walls perpendicular to surfaces "a", "b", and "c" from arc axis to apex of the optics.
f. Contoured optical flat side walls at selected angles with surfaces "b", "c" and "d" from arc axis to opening of the optics.
g. Absorption filter elements.
h. Dichroic filter elements (used with surface "a").

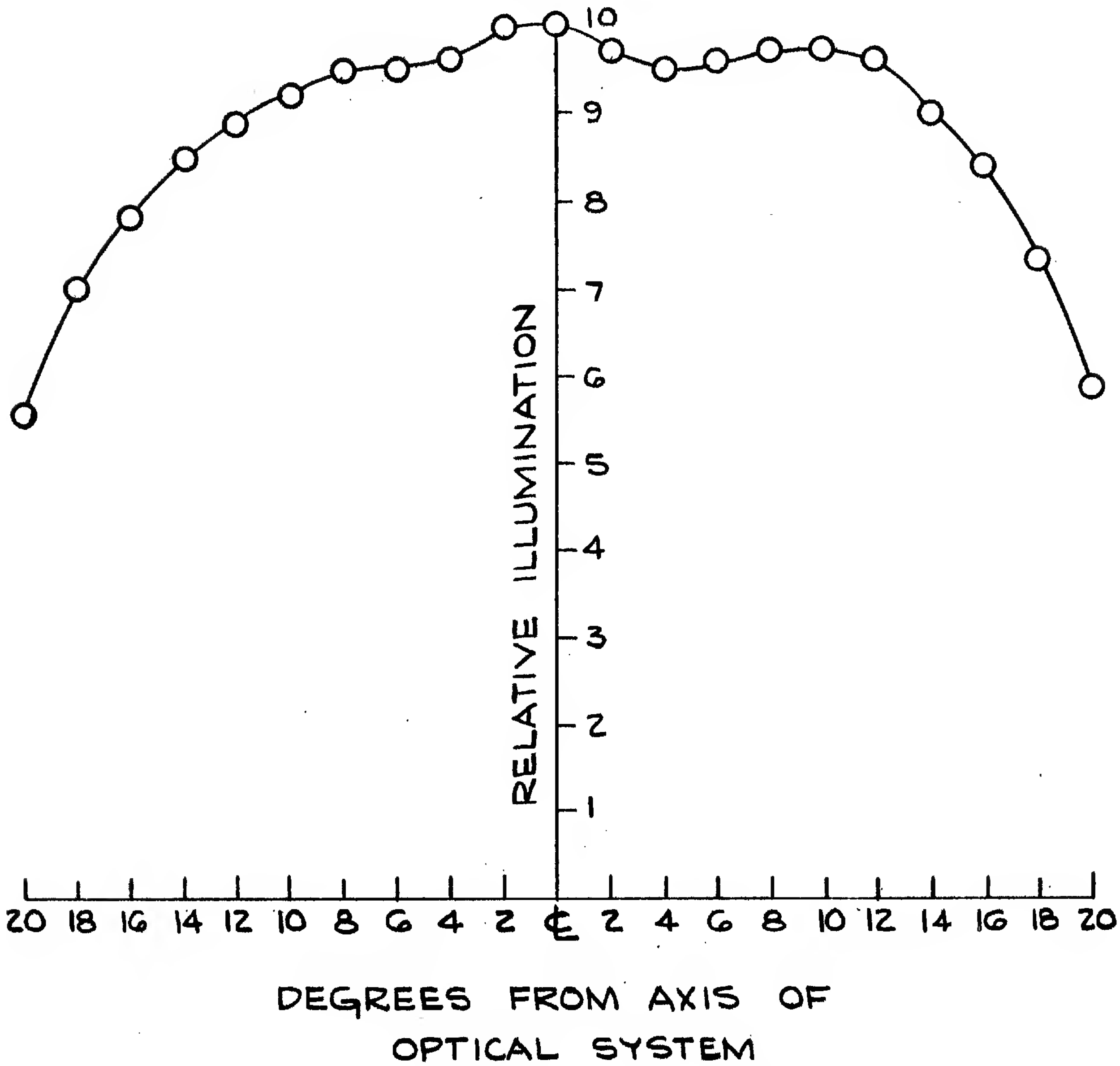

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FIGURE 10 Illuminated Area Lateral Distribution Achieved with a 4° x 40° Prototype Optical System

1. Mirrored end wall.
2. Saddle.
3. Concentric mirror.
4. Electrode assembly positioning hole.
5. Saddle mirrors.
6. Location of parabolic mirrors.
7. Trellis networks.
8. 23-degree dichroic mirror position.
9. 18-degree beam-splitter mirrors.
10. Grooved filter guides.
11. Air duct connections.

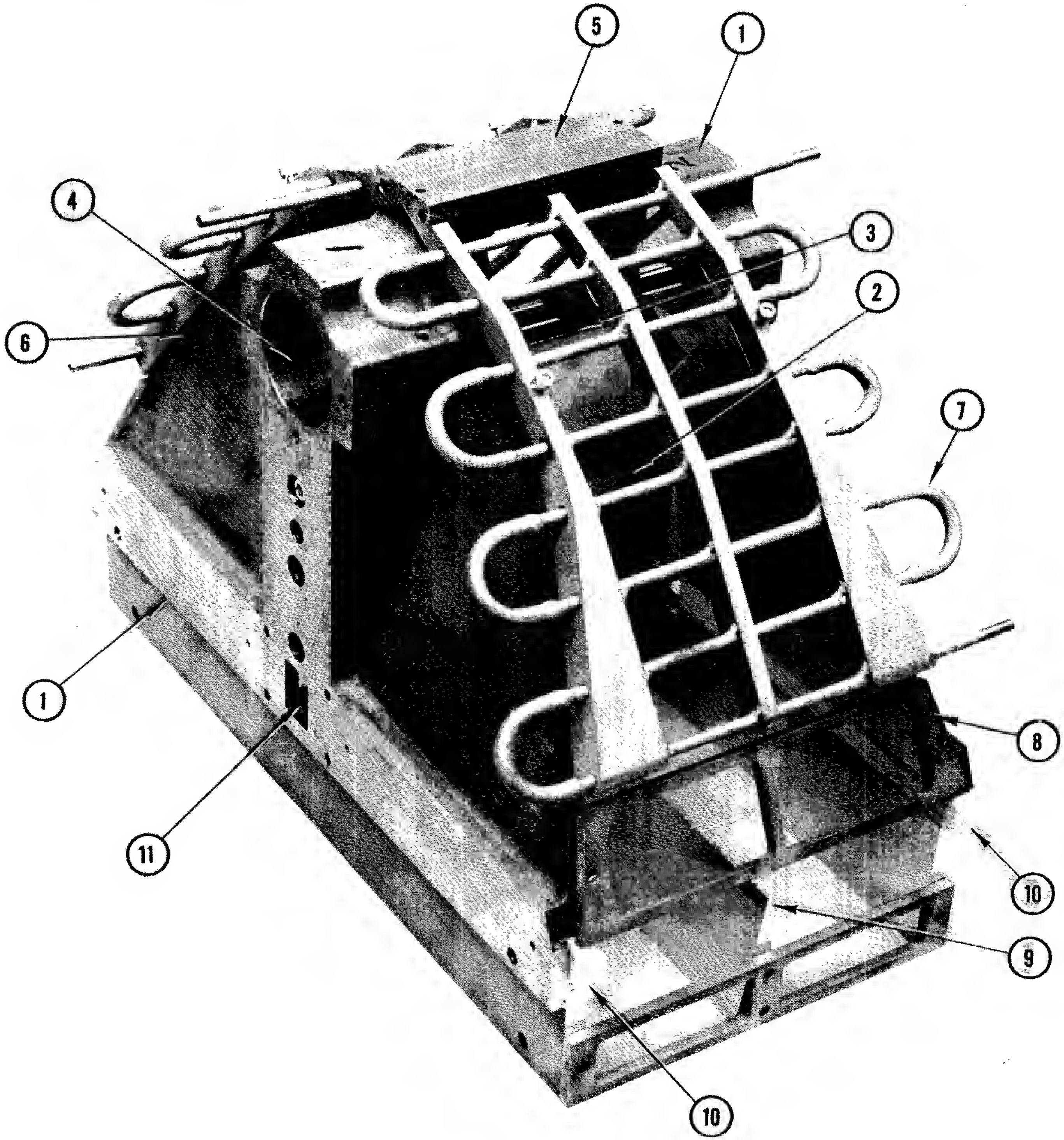

FIGURE 11 Reflector Assembly for 35 kw Illumination System

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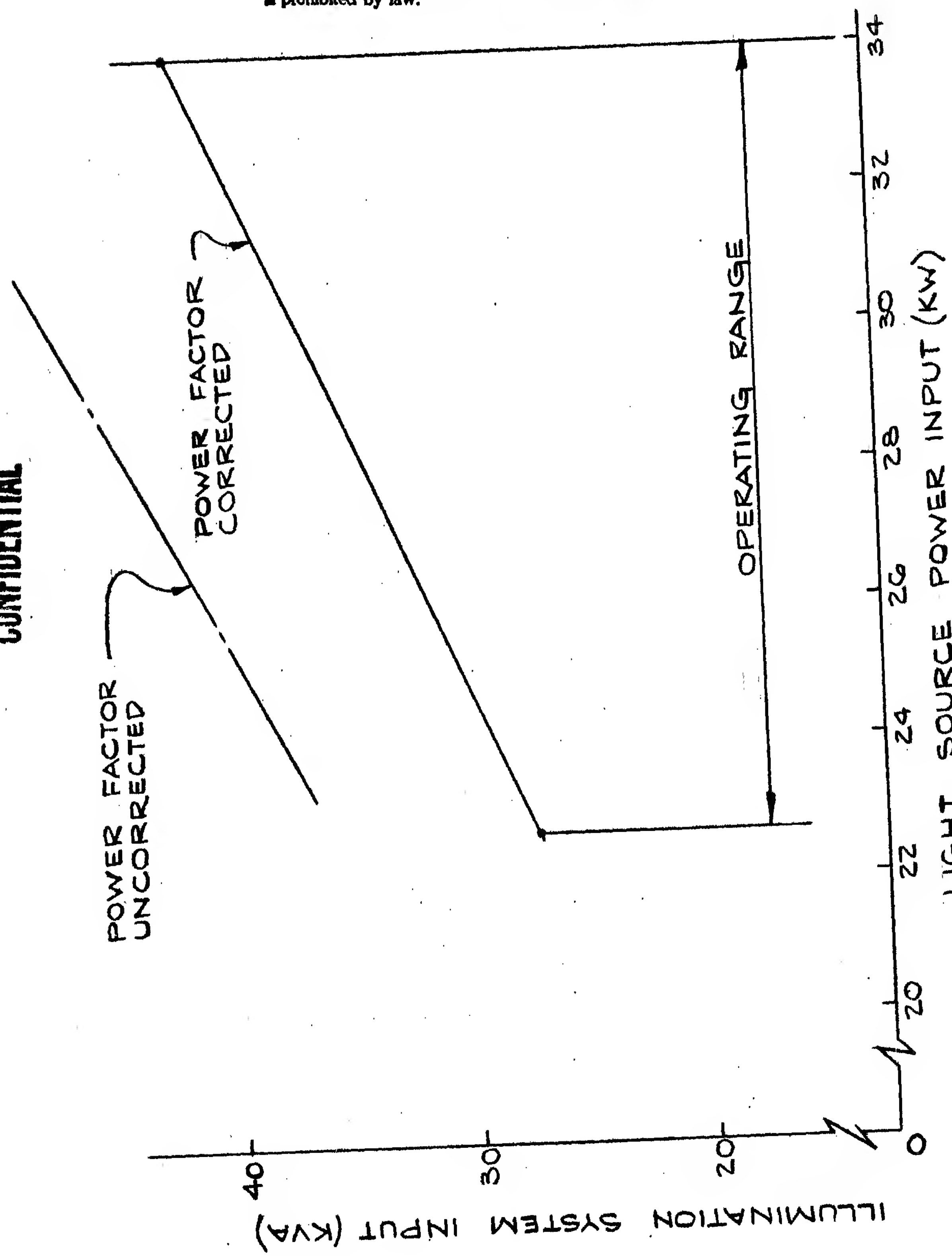

FIGURE 12 Input kva to the Illumination System versus Input Power to the Radiation Source

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1. Main power distribution box.
2. Saturable core reactor
3. Transformer.
4. Rectifier.
5. Power factor correction capacitors.

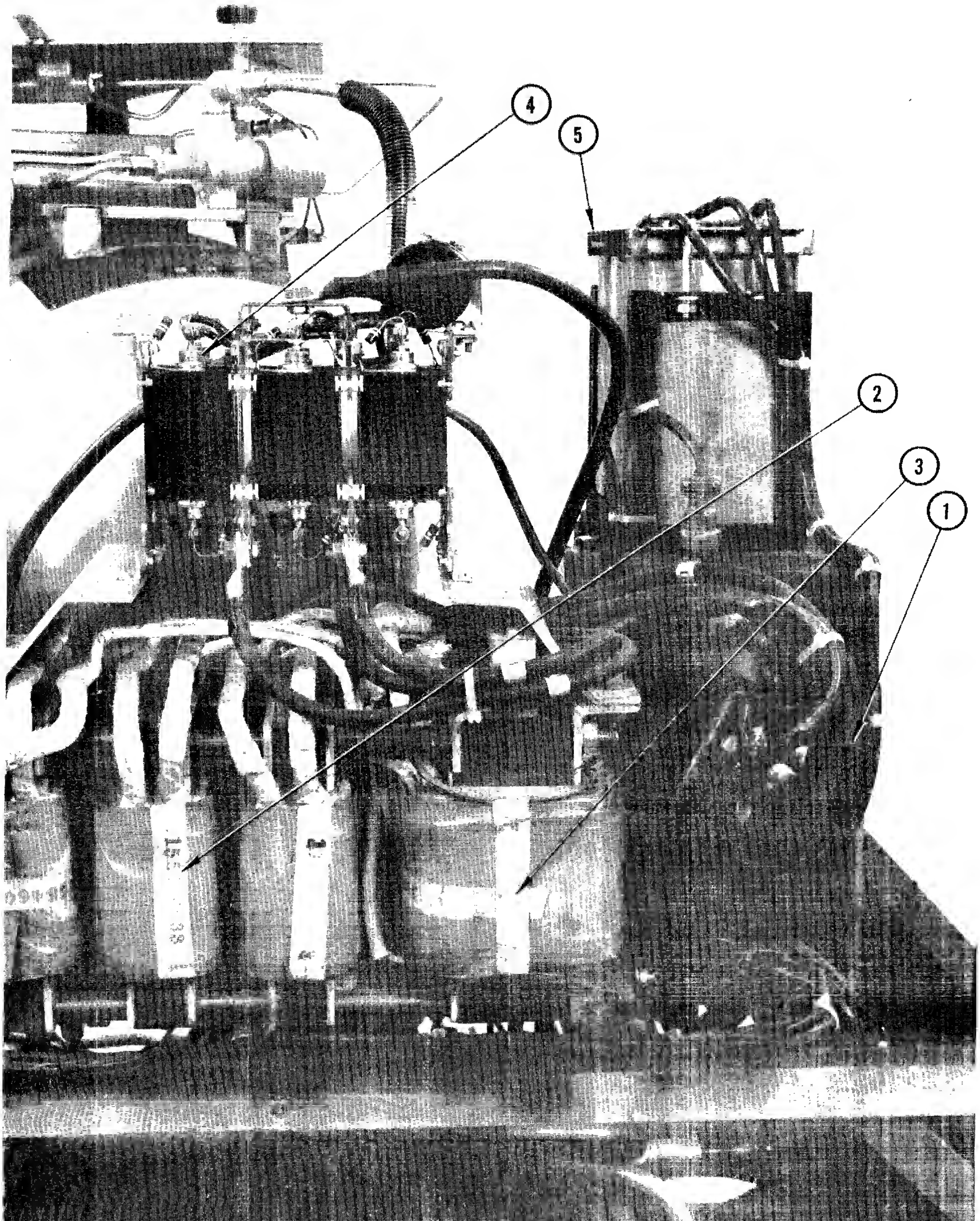

FIGURE 13 35 kw Illumination System Power Supply Elements

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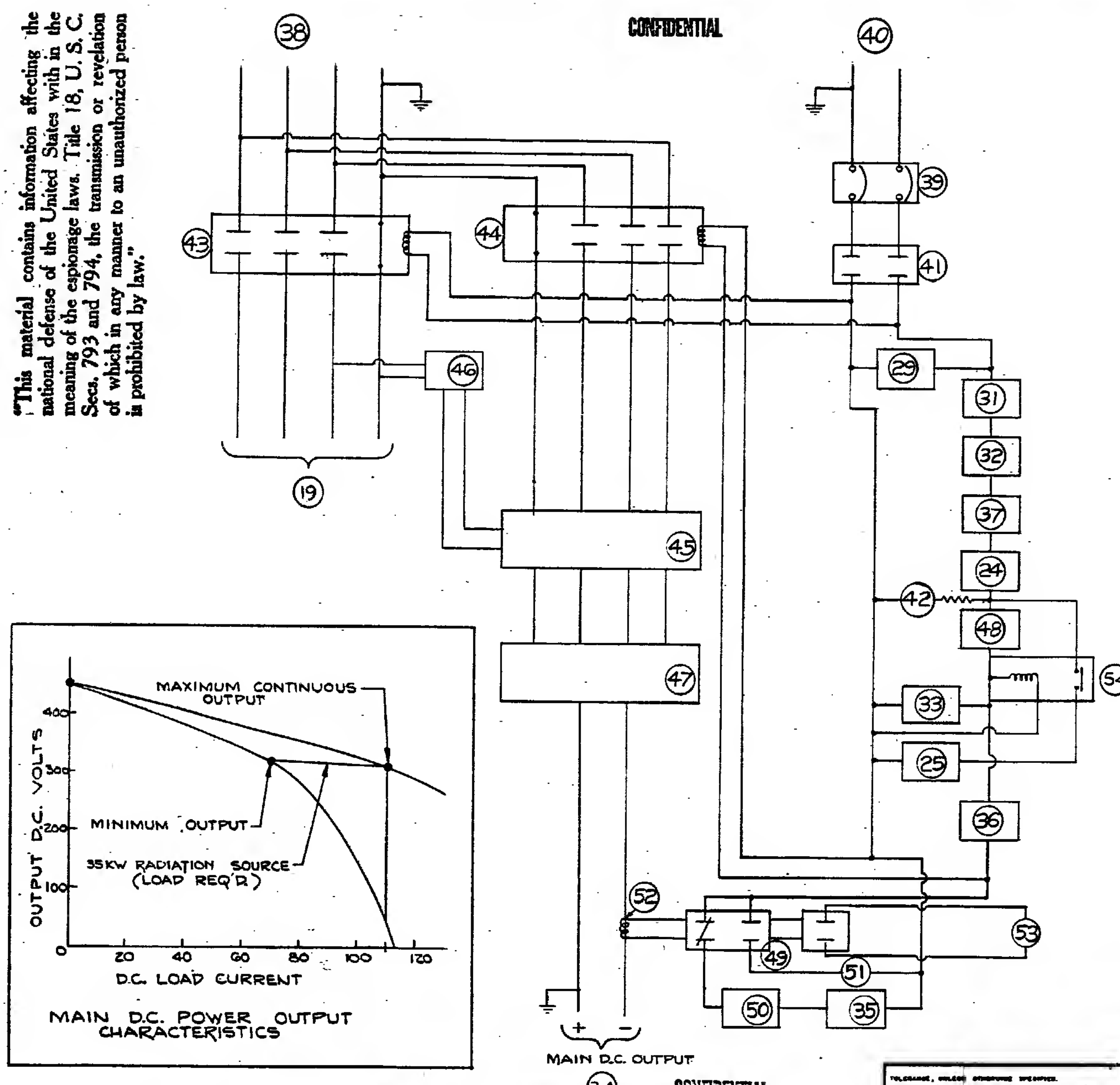

BILL OF MATERIAL

ITEM	DESCRIPTION
19	AUXILIARY POWER TO GAS AND COOLANT PUMPS
24	GAS SUPPLY PRESSURE SWITCH, CLOSE AT 350 P.S.I.G.
25	GAS SUPPLY SOLENOID ON-OFF VALVE.
29	N.O. 2WAY SOL. VALVE FOR SCOOP LOCKS.
31	COOLANT TEMP. SWITCH.
32	COOLANT FLOW SWITCH.
33	SOL. VALVE TO ACTUATE AIR SCOOP.
34	450 V. DC POWER TO ARC.
35	SOL. VALVE TO PUSH-START ARC.
36	CHAMBER PRESSURE SWITCH, CLOSE AT 140 P.S.I.G.
37	POWER SUPPLY TEMP. SWITCH, OPEN AT 350°F.
38	AIRCRAFT MAIN POWER, 3φ 400 c.p.s.-115/208 V.
39	AIRCRAFT 28 V. DC CIRCUIT BREAKER
40	AIRCRAFT 28 V. DC.
41	PILOT "READY" SWITCH
42	PILOT "READY" LIGHT
43	AUXILIARY POWER CONTACTOR
44	ARC POWER CONTACTOR, 3 POWER RELAYS
45	50 KVA. SATURABLE CORE TRANSFORMER/REACTOR
46	SATURATING CURRENT RHEOSTAT (INTENSITY CONTROL)
47	SILICON DIODE RECTIFIER BRIDGE
48	PILOT "ON" SWITCH
49	ARC CURRENT RELAY
50	DELAY RELAY
51	ARC "ON" LIGHT
52	REED RELAY TO CLOSE AT 70 AMPS ARC CURRENT
53	N.O. CONTACTS TO SWITCH EXTERNAL EQUIP.
54	GAS CUTOFF, DELAY RELAY (DELAY OFF ADJUSTABLE)

F. MANNING 8-31-66

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AIRBORNE LIGHT SOURCE POWER AND CONTROL SYSTEM. CONTRACT AF33(615)-3437

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FIGURE 14 Wiring Diagram for 35 kw Power Supply and Pilot's Control Box

FIGURE 15 Pilot's Control Box for 35 kw Illumination System

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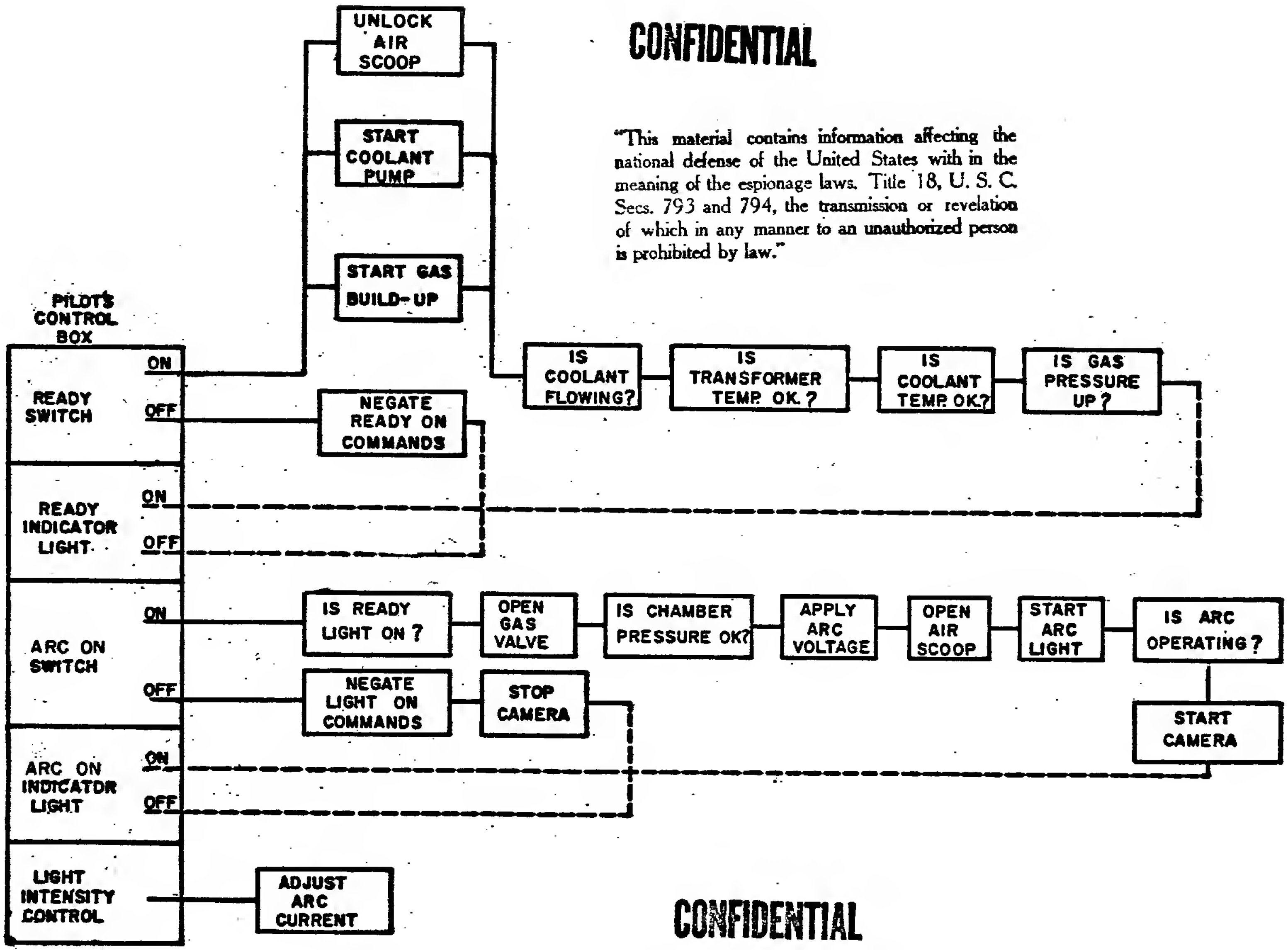

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FIGURE 16 Functional Schematic of Pilot's Control Box for 35 kw Illumination System

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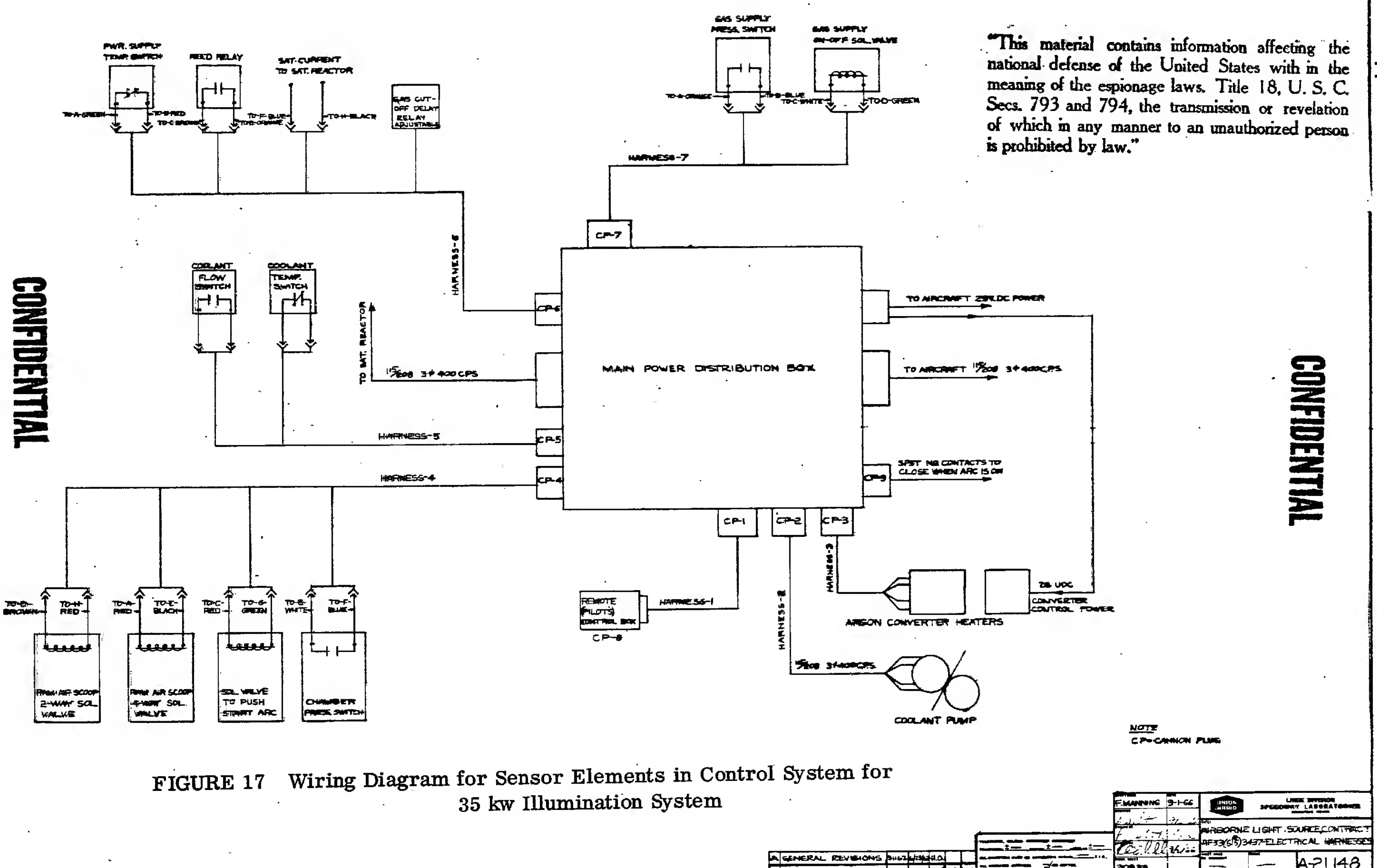

FIGURE 17 Wiring Diagram for Sensor Elements in Control System for 35 kw Illumination System

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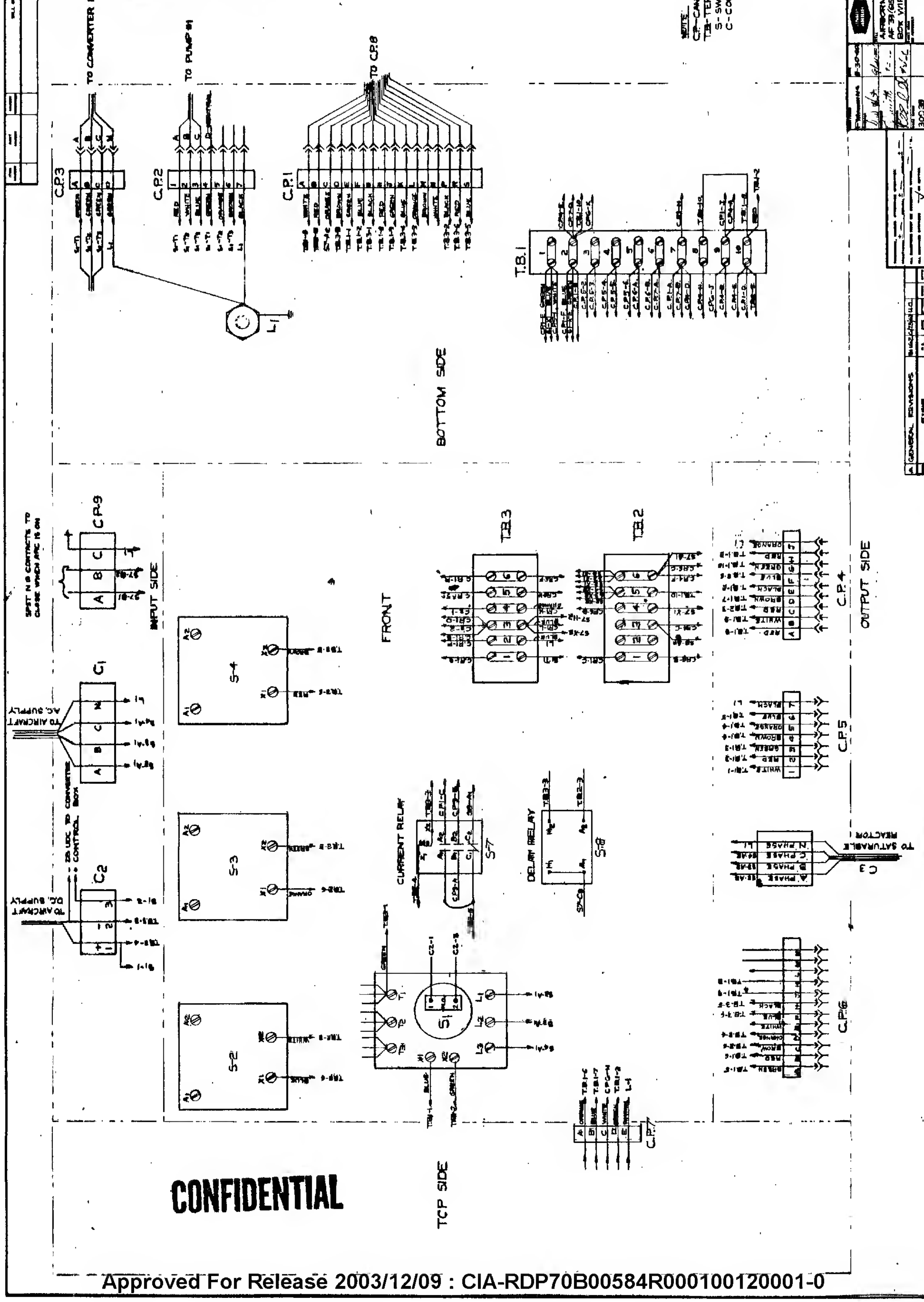

FIGURE 18 Wiring Diagram for Main Power Distribution Box for 35 kw Illumination System

1. Liquid argon coolant fill panel.
2. Gaseous argon pressure regulator.
3. Pressure safety valve.
4. Liquid argon storage vessel.
5. Liquid-to-gas converter switch box.
6. Gas superheaters.
7. Finned delivery tube.

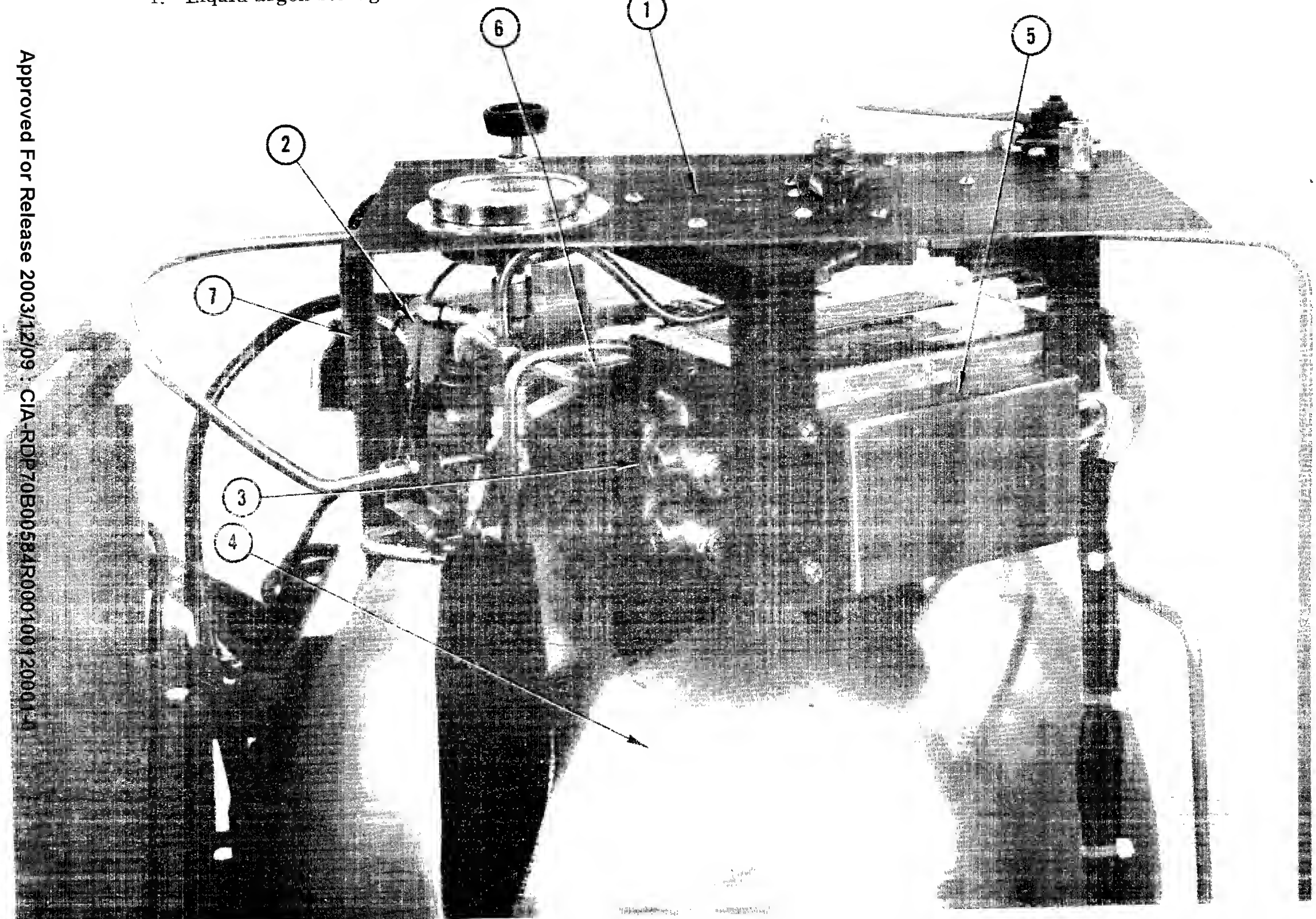

FIGURE 19 35 kw Illumination System Gas Supply Elements

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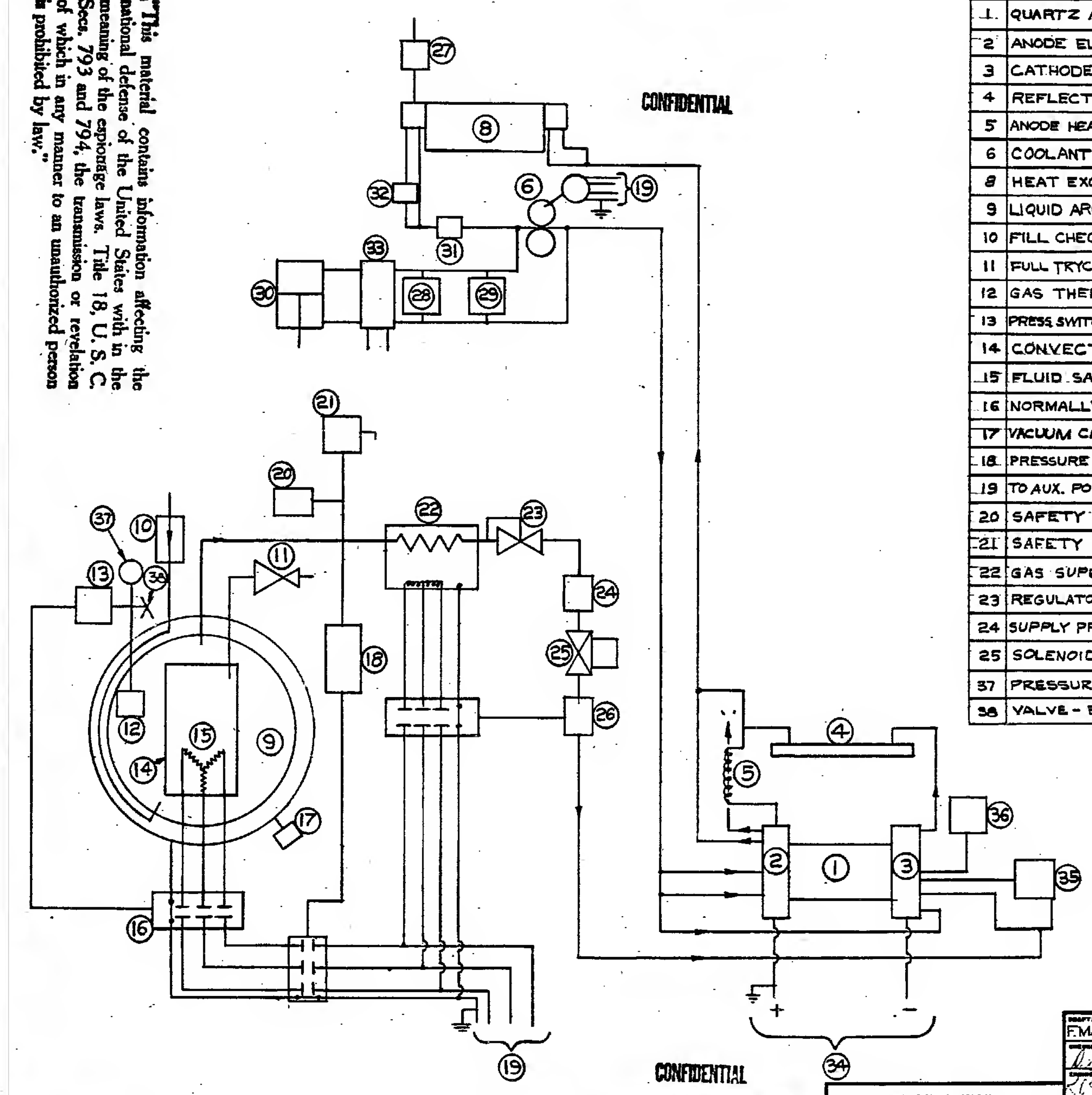

BILL OF MATERIAL

Item No.	Description	Item No.	Description
1	QUARTZ ARC TUBE	26	TEMPERATURE SWITCH FOR SUPERHEATERS
2	ANODE ELECTRODE	27	COOLANT FILL CAP
3	CATHODE ELECTRODE	28	AIR SCOOP HYD. LOCKS
4	REFLECTOR	29	2-WAY NO. SOL. VALVE FOR SCOOP ACTUATOR
5	ANODE HEAT EXCHANGER	30	SCOOP ACTUATOR
6	COOLANT PUMP	31	COOLANT TEMP. SW. OPEN 180°F.
8	HEAT EXCHANGER	32	COOLANT FLOW SWITCH CLOSE AT 2 GPM.
9	LIQUID ARGON CONTAINER	33	4 WAY SOLENOID VALVE FOR SCOOP ACTUATOR
10	FILL CHECK VALVE	34	TO ARC POWER, 450V.DC RECTIFIER BRIDGE
11	FULL TRYCOCK AND VENT VALVE	35	3-WAY SOLENOID VALVE FOR PUSH START OF ARC
12	GAS THERMOMETER	36	CHAMBER PRESSURE SWITCH, CLOSE AT 140 PSIG.
13	PRESS. SWITCH (OPEN 50 PSIG, CLOSED 40 PSIG.)		
14	CONVECTOR		
15	FLUID SATURATING HEATERS		
16	NORMALLY OPEN CONTACTOR		
17	VACUUM CASING BURST DISC AND VACUUM PINCHOFF		
18	PRESSURE SWITCH; CLOSE AMB. TO 495 PSIG, OPEN 500 PSIG UP.		
19	TO AUX. POWER CONTACTOR, 208 V. 3φ 400 CPS		
20	SAFETY VALVE, 600 PSIG.		
21	SAFETY VALVE, 550 PSIG.		
22	GAS SUPERHEATER		
23	REGULATOR, 400 P.S.I.G.		
24	SUPPLY PRESSURE SWITCH, CLOSE 350 P.S.I.G., OPEN 335 P.S.I.G.		
25	SOLENOID VALVE		
37	PRESSURE GAUGE - EMPTY CUTOFF PRESSURE MONITOR		
38	VALVE - EMPTY CUTOFF FILL		

A	GENERAL REVISIONS	311G2	6/22/67	H.O.

F. MANNING 8-31-66

UNION CARBIDE — LINDE DIVISION, SPEEDWAY LABORATORIES, INDIANAPOLIS, INDIANA

AIRBORNE LIGHT SOURCE
GAS AND COOLANT SYSTEMS
CONTRACT AF33(615)3437

30938

B-21147

FIGURE 20 Flow Schematic for the Gas and Coolant Systems for 35 kw Illumination System

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1. Water pump.
2. Heat exchanger.
3. Ram air scoop.
4. 35 kw radiation sou

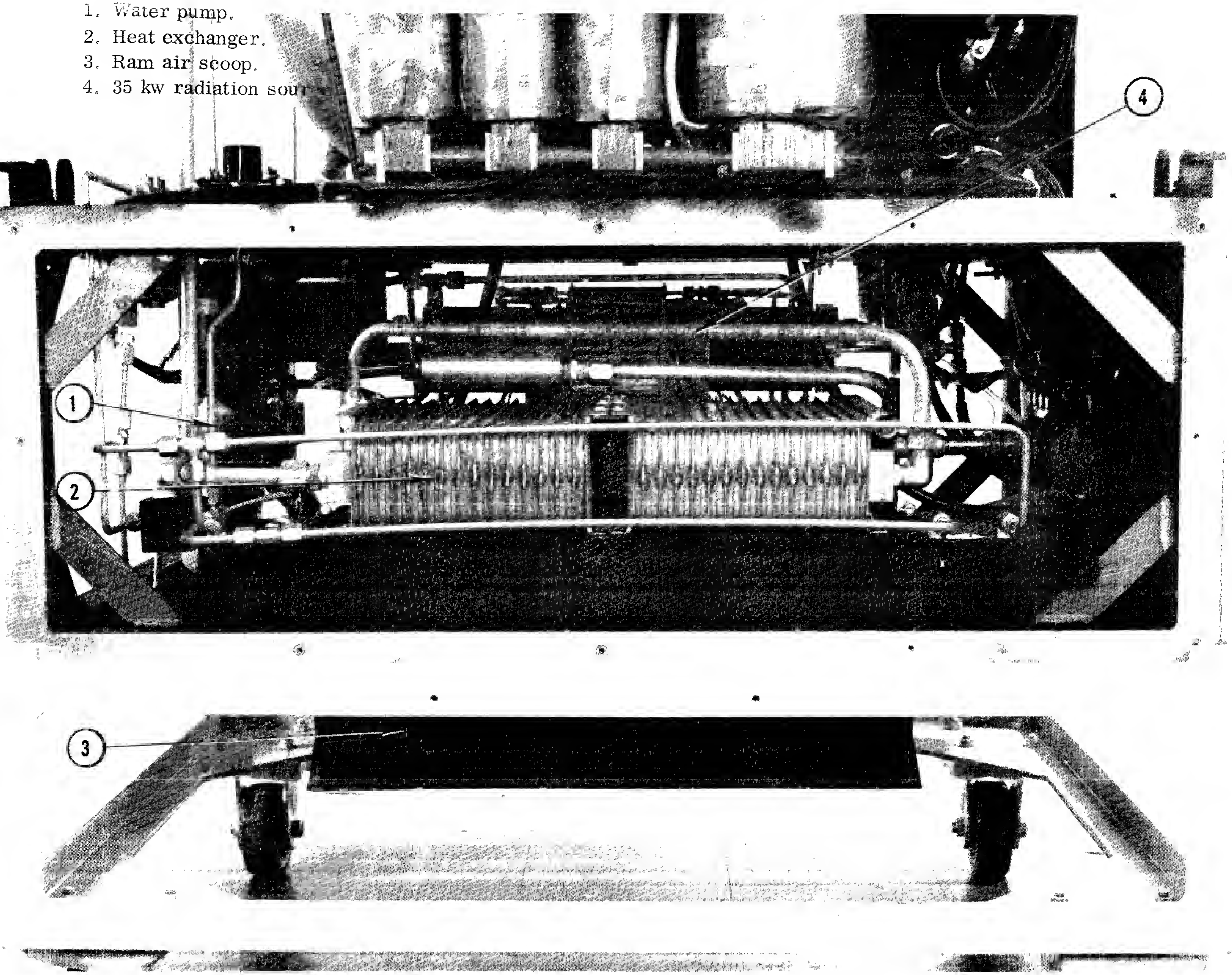

FIGURE 21 35 kw Illumination System Coolant Loop Elements

1. Water fill connection.
2. Coolant fill valve.
3. Coolant vent valve.
4. Liquid argon fill connection.
5. Gas thermometer valve.
6. Gas thermometer port.
7. Gas thermometer pressure gauge.

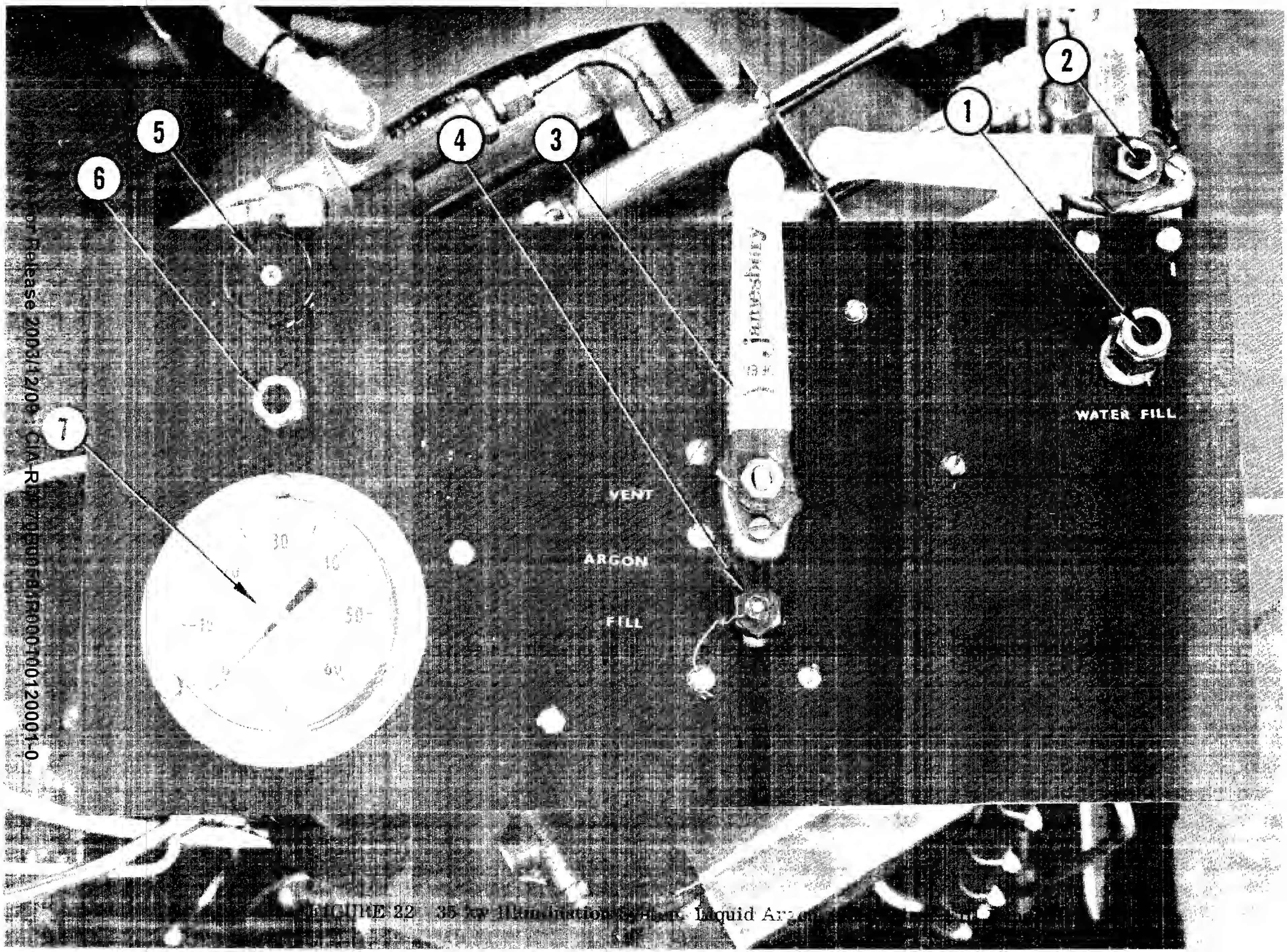

FIGURE 22 35 kw Illumination System. Liquid Ar

1. Water container for filling system.
2. Water transfer hose.
3. Service box.
4. Valve "B".
5. Valve "A".

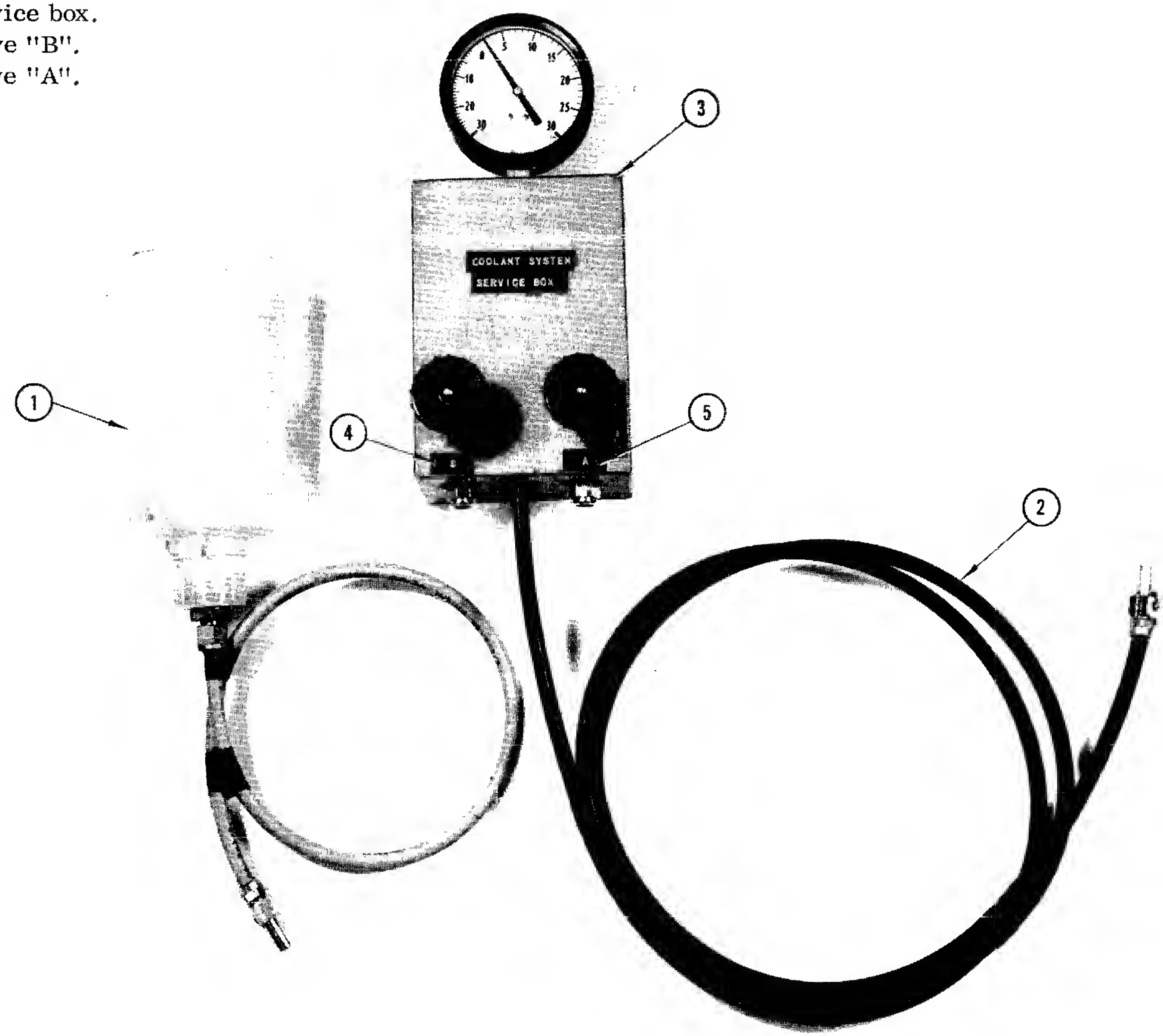

FIGURE 23 Coolant System Service Box

1. Coolant drain valve.
2. Cool
3. Exh

4. 35 kw radiation source.

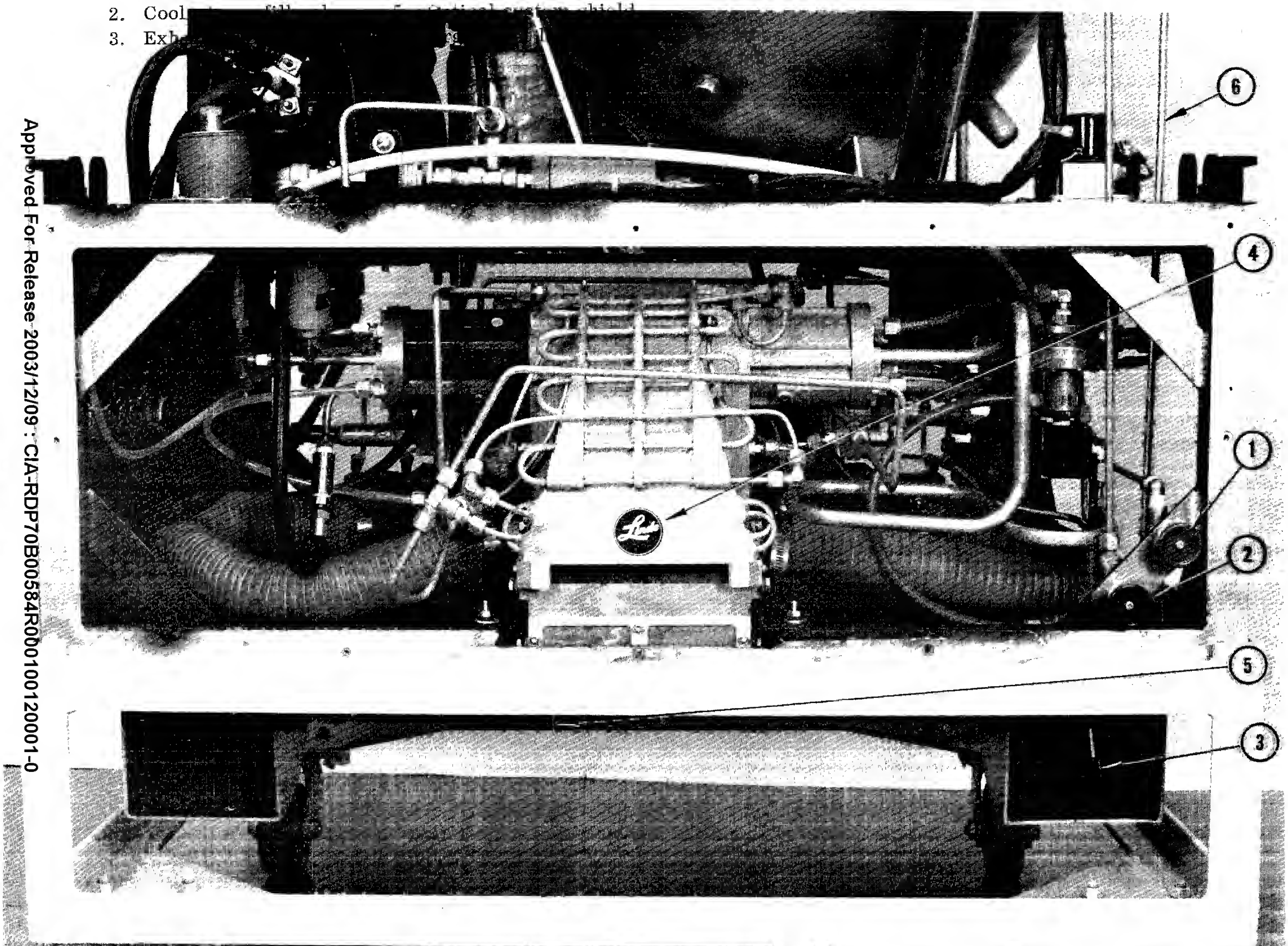

FIGURE 24 35 kw Radiation Source in Illumination System

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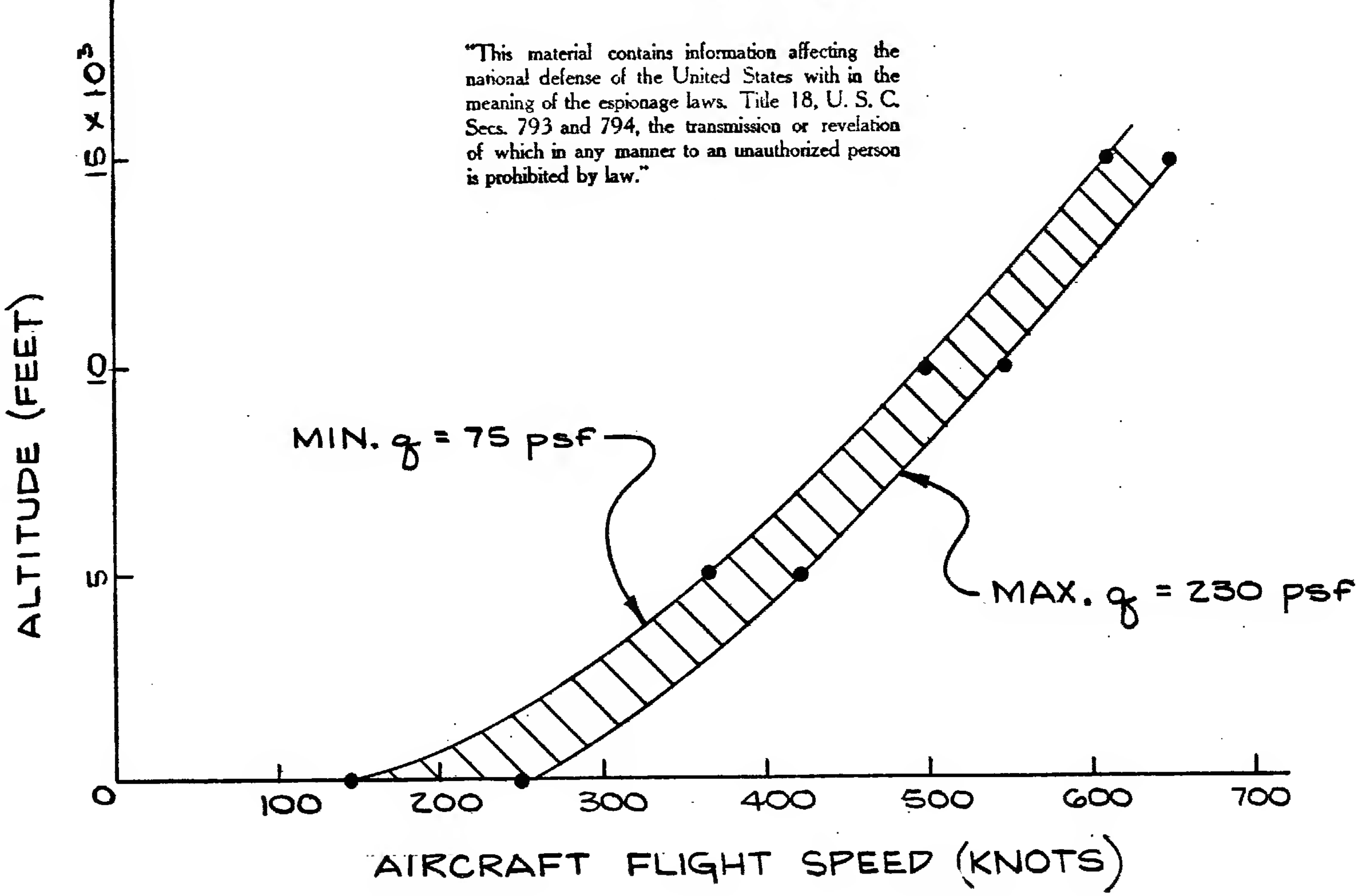

FIGURE 25 - Aircraft Altitude Velocity Envelope for 35 kw Illumination System Operating at Maximum Power

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